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FINAL PROJECT REPORT

RESERVOIR CONFIRMATION OF THE BUCKEYE POWER PLANT AREA

Wildhorse State 36 Confirmation Well, Northwest Geysers

Prepared for: California Energy Commission

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PREFACE

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Reservoir Confirmation of the Buckeye Power Plant Area, Wildhorse State 36 Confirmation Well, Northwest Geysers is the final report for the Wildhorse State 36 Confirmation Well Project (Grant Award Number GEO-07-006) conducted by Geysers Power Company ("Calpine"). The information from this project contributes to Energy Research and Development Division's Resource Assessment Studies.

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ABSTRACT

The Wildhorse State 36 well was drilled as one of three wells needed to confirm financing of a proposed new 33 megawatt Buckeye Power Plant in the northwest area of The Geysers geothermal field in Sonoma County, California. The project was co-funded by the California Energy Commission. Wildhorse State 36 was drilled, completed and tested between October 2009 and December 2010. The well was drilled to a depth of 12,340 feet at a cost of about $7.5 million.

A resource was found but proved insufficient to justify constructing a new generator in the Buckeye Power Plant area. The power density estimated in previous studies and the hypothesis that the Buckeye area exists in a separate structural zone or "compartment" isolating it from nearby areas were not confirmed. Testing results showed that the Wildhorse State 36 well may have the capacity to produce less than 1.5 megawatts of equivalent steam. This does not justify investing in the new deep wells that would be needed to support construction of a new generator. Wildhorse State 36 was completed as an injector well but cannot serve as an injector in an enhanced geothermal system because it was drilled through a deep high temperature reservoir into a lower temperature zone. Steam from the well could be collected and piped to existing power plants. The geochemical, temperature, rock type, geologic structure, and isotope data gained from the tests and analyses on this well and other nearby wells will be valuable in planning future exploration in the northern part of The Geysers.

Keywords: California Energy Commission, geothermal, The Geysers, northwest Geysers, geology, geochemistry, isotopes, well test, exploration, Geysers development, reservoir compartmentalization.

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EXECUTIVE SUMMARY

Introduction

The Wildhorse State 36 Confirmation Well Project was part of a resource development effort that Geysers Power Company, LLC ('Calpine") was implementing in the northwest portion of The Geysers geothermal steam field in Sonoma County, California. Calpine wanted to determine if an economically viable resource existed to support a proposed electrical power plant on Ottoboni Ridge between the existing Calpine Units 7 and 8 and the Aidlin Power Plants. The resource for the proposed Buckeye Power Plant was a 1000-acre area northwest of existing production, about one mile southeast of the Aidlin development area. The Buckeye Power Plant area is surrounded on three sides by proven steam fields and had been previously explored by temperature gradient holes and a deep exploration well known as Wildhorse 2. Wildhorse State 36 was one of three confirmation wells drilled and tested to determine the production potential of the resource, and was necessary to secure financing for the power plant. Calpine subsequently drilled additional confirmation wells, Wildhorse State 71 and Wildhorse State 34 from the same drilling pad. The Wildhorse State 36 project was co-funded by the California Energy Commission. Wildhorse State 71 and Wildhorse State 34 were funded entirely by Calpine.

Project Purpose

The primary goal of this project was characterizing the prospective reservoir's production flow rates, temperature, pressure, thickness, permeability, and fluid chemistry to help determine if the resource could economically support the proposed Buckeye Power Plant. The project was also intended to test the hypothesis that reservoir pressures may not have significantly declined in the Buckeye Power Plant area as they have in the main Geysers reservoir to the southeast because the Buckeye Area was isolated from the main portion of The Geysers by intervening structural discontinuities in the reservoir. The area could be developed with minimum pressure interference to and from the surrounding steam fields if the confirmation wells demonstrated that the Buckeye Power Plant area reservoir existed in a "compartment" that was partially isolated from the main portion of the declined Geysers reservoir.

An additional goal was demonstrating that injecting water into the high temperature zone in the Buckeye Power Plant area could create an enhanced geothermal system.

The specific objectives of the project were to drill, complete, and test Wildhorse State 36, and to collect gas and cuttings samples for chemical and isotopic analyses.

Project Results

Wildhorse State 36 was drilled to a depth of 12,340 feet at a cost of about \$7.5 million. The initial drilling rig mobilization, drilling, and drilling rig demobilization cost about \$7.05 million. The well was drilled and completed in 102 days. A work-over and clean-out of the well became necessary, costing an additional \$0.44 million and 10 additional days.

The bottom of the hole was 3,470 feet South 25 degrees (°) West from the wellhead. Below 9,000 feet the angle of the wellbore increased rapidly from about 35° to over 48°, causing the well trajectory to move to the south-southwest.

Cemented well casing was set from the surface to 3,177 feet. Slotted/blank 8-5/8 inch (") casing and 7" liner was set from 2,883 feet to 12,336 feet.

Several factors combined to complicate the project. During the initial "rig" testing of the well, drilling mud from the nearby Wildhorse State 71 well broke through and into Wildhorse State 36. The breakthrough caused an obstruction in the liner, which required cleaning out the well bore.

Testing included three short-term rig tests, a pressure-temperature-spinner log, a static pressure-temperature log, and a three-day isochronal test. Isochronal refers to a multirate test designed as a series of drawdown and buildup sequences at different drawdown flow rates, with each drawdown of the same duration and each buildup reaching stabilization at the same pressure as at the start of the test. Pressures were monitored in nearby wells to determine if transient pressures could be measured.

Drilling cuttings were collected and logged continuously. Temperatures were recorded intermittently with maximum reading thermometers during drilling. Whole-rock cuttings were collected and analyzed for the isotope oxygen-18. Hydrogen sulfide was measured routinely while drilling. Condensate, steam and downhole fluid samples were collected and analyzed for noncondensible gases, chloride and boron, oxygen-18 and deuterium isotopes and major ions.

The well did not confirm sufficient steam reserves to justify the financing and construction of the proposed Buckeye Power Plant. Eleven steam entries into the well were encountered but testing found them to be capable of producing less than 1.5 megawatts of steam. Water production began with two steam entries at 6,588 feet and 6,651 feet, producing 10-15 barrels per hour of water and 14.3 kilo pounds per hour of steam. Water production ceased at about 10,783 feet. A "thief" zone at about 3,500 feet into which steam flow from deeper in the well was partially lost was observed.

The top of the steam reservoir was determined to be at a depth of 4, 669 feet but the steam was depleted to a depth of 9,285 feet. A "normal" temperature steam reservoir (440°F - 480°F) was encountered between 6,588 feet and about 9,400 feet, which was also observed in other portions of the Northwest Geysers. Highly superheated steam (80°-150° of superheat) was being produced below the wet stream entry at 6,651 feet. A high temperature zone with maximum temperatures of 538°F - 624°F was encountered below 9,400 feet in metamorphic (hornfelsic metagraywacke) rocks. The well was drilled out of the high temperature zone and bottomed into "normal" temperature rocks apparently associated with the Mercuryville Fault Zone. The fluid temperatures at the bottom of the well were similar to those found in the main Geysers reservoir. Static pressure/temperature logging detected a boiling column of water between 9,400 feet and 10,970 feet.

Isochronal testing of Wildhorse State 36 showed that it was capable of producing 31.1 kilo pounds per hour of steam in June 2010 and 26 kilo pounds per hour in December 2010 (both normalized to 100 pound-force per square inch gauge). Water built up in the wellbore and blocked several of the deep steam entries while the wellbore was shut-in between June and December.

The shut-in wellhead pressure following the isochronal test increased from 318.45 pound-force per square inch gauge in December 2010 to 333.75 pound-force per square inch gauge in March 2011. Analyses of Horner build-up plots resulted in a calculated static wellhead pressure of 334 pound-force per square inch gauge. Horner build-up plots of the shut-in pressures following the December 2010 isochronal testing indicated that the permeability-thickness product was about 10,000 millidarcy-feet. This value was on the low end of the range for the Northwest Geysers, which was 5,000-250,000 millidarcy-feet.

The total noncondensible gas concentration of steam collected during the isochronal testing was analyzed as 1.4 to 1.5 percent by weight. Higher noncondensible gas concentrations were associated with steam entries at 6,651 feet and 8,295 feet. Noncondensible gas values dropped dramatically after 9,285 feet. Isotopic analyses of whole-rock cuttings, condensate and water indicated that the steam produced from 6,588 feet to about 10,780 feet originated by breakthrough from the deep entries in proximity to the Mercuryville Fault. Major ion chemistry analyses indicated that the deep water was high temperature geothermal water that had been concentrated somewhat by boiling. The boiling water column was apparently caused by the development of a two-phase geothermal system with upward flow to the thief zone.

The reservoir appeared to have been depleted by the three surrounding steam fields by about 165 pound-force per square inch gauge. Pressure monitoring at the nearby confirmation wells Wildhorse State 71 and Wildhorse State 34 indicated pressure interference and reservoir interconnection.

The basis for this report was a detailed internal report prepared by Joe Beall (dated April 6, 2011) that was submitted to the California Energy Commission separately. Information from other wells was included solely for technical clarification of the conclusions.

Steam from Wildhorse State 36 could be collected and piped to existing Units 7 and 8 or to the proposed Wildhorse Power Plant. The well could also be used for injection. The well is not a candidate for deep injection to create an enhanced geothermal system because it was drilled out of the high temperature zone.

Project Benefits

The geochemical, temperature, rock type, geologic structure, and isotope data gained from the tests and analyses on this well and other nearby wells will be valuable in planning future exploration in the northern part of The Geysers. Increasing geothermal capacity in California would benefit the state because geothermal energy does not produce greenhouse gas emissions or other emissions that cause air pollution.

CHAPTER 1: Background

1.1 Introduction

The purpose of the Wildhorse State 36 (WHS-36) Confirmation Well Project was to confirm the economic viability of a geothermal reservoir to supply a new electrical generator (power plant) at The Geysers. The resource for the proposed plant is a 1000-acre area that had been previously explored by temperature gradient holes (TGH) and a deep exploration well known as Wildhorse 2 (WH-2). The area is surrounded on three sides by proven steam fields. The proposed electrical generator is known as the Buckeye Power Plant, planned to be located on Ottoboni Ridge in the Northwest area of The Geysers.

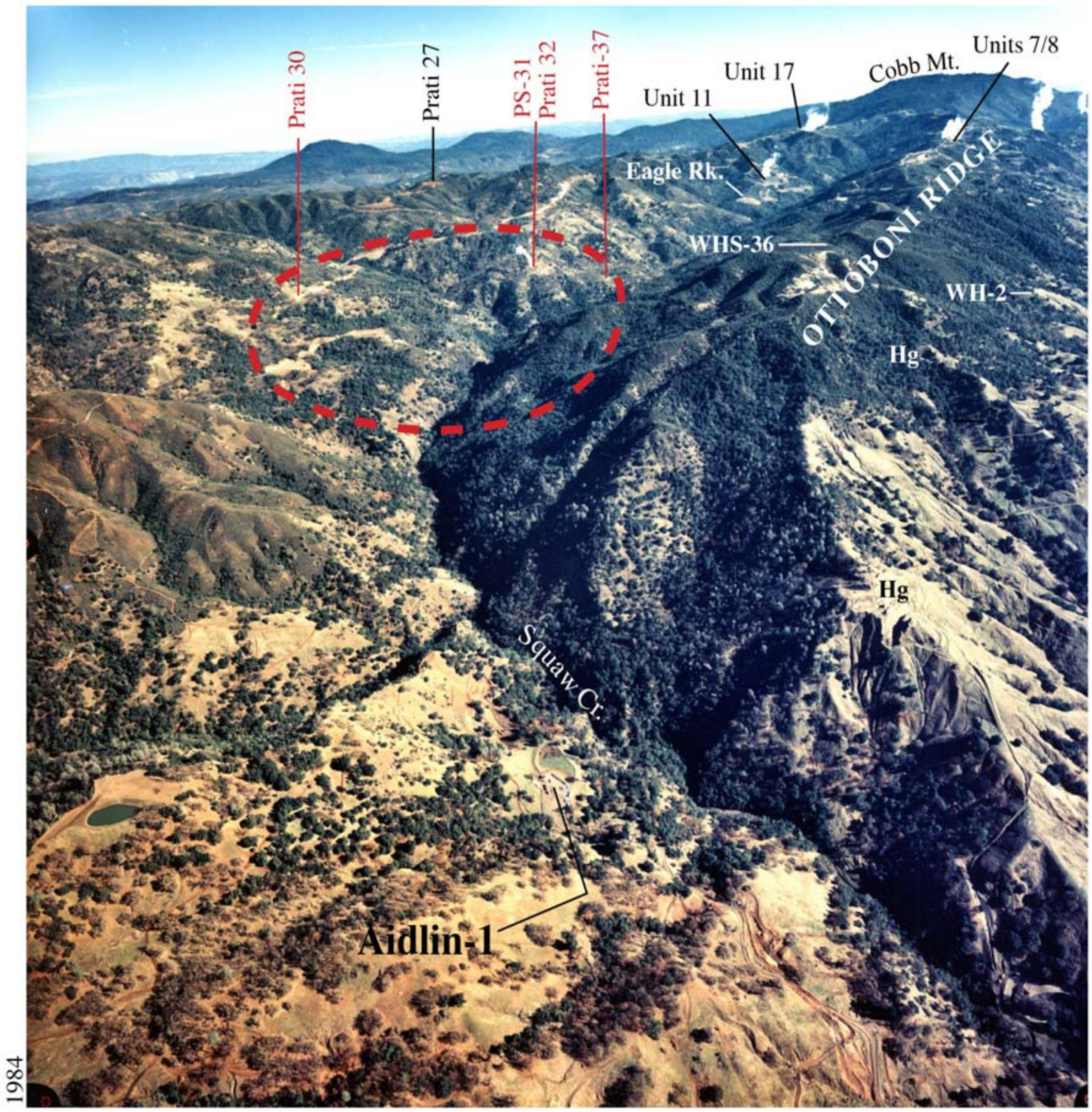
WHS-36 was originally planned as one of two confirmation wells necessary for Geysers Power Company, LLC (“Calpine”) to determine if financing and construction of the Buckeye Power Plant was economically justified. The second confirmation well is Wildhorse State 71 (WHS-71). Because of problems encountered during drilling the first two wells and results that were disappointing, a third confirmation well, Wildhorse State 34 (WHS-34) was drilled. Both WHS-34 and WHS-71 were drilled from the same drilling pad following the drilling of WHS-36. WHS-36 was co-funded by the California Energy Commission (CEC). WHS-71 and WHS-34 were funded entirely by Calpine.

This report summarizes the history, activities, testing, and analyses associated with WHS-36. Appendix A includes internal drilling and testing reports. Appendix B consists of the geologic log for WHS-36, prepared by Tecton Geologic. Appendix C contains the analytical data. The basis for this report is a detailed internal report prepared by Joe Beall (dated April 6, 2011) that has been submitted to the California Energy Commission separately. Information from other wells is included solely for technical clarification of the conclusions.

Figure 1 is an aerial photo showing the location of WHS-36 and Wildhorse 2 (WH-2) on Ottoboni Ridge.

Figure 2 is a general location map of The Geysers area showing power plants and creeks mentioned in this report. The WHS-36 well is about 500‘northwest of the proposed Buckeye Power Plant location.

Figure 1: Aerial Photo of the Northwest Geysers



Northwest Geysers
EGS Demonstration Area

Figure 2: General Location Map of The Geysers

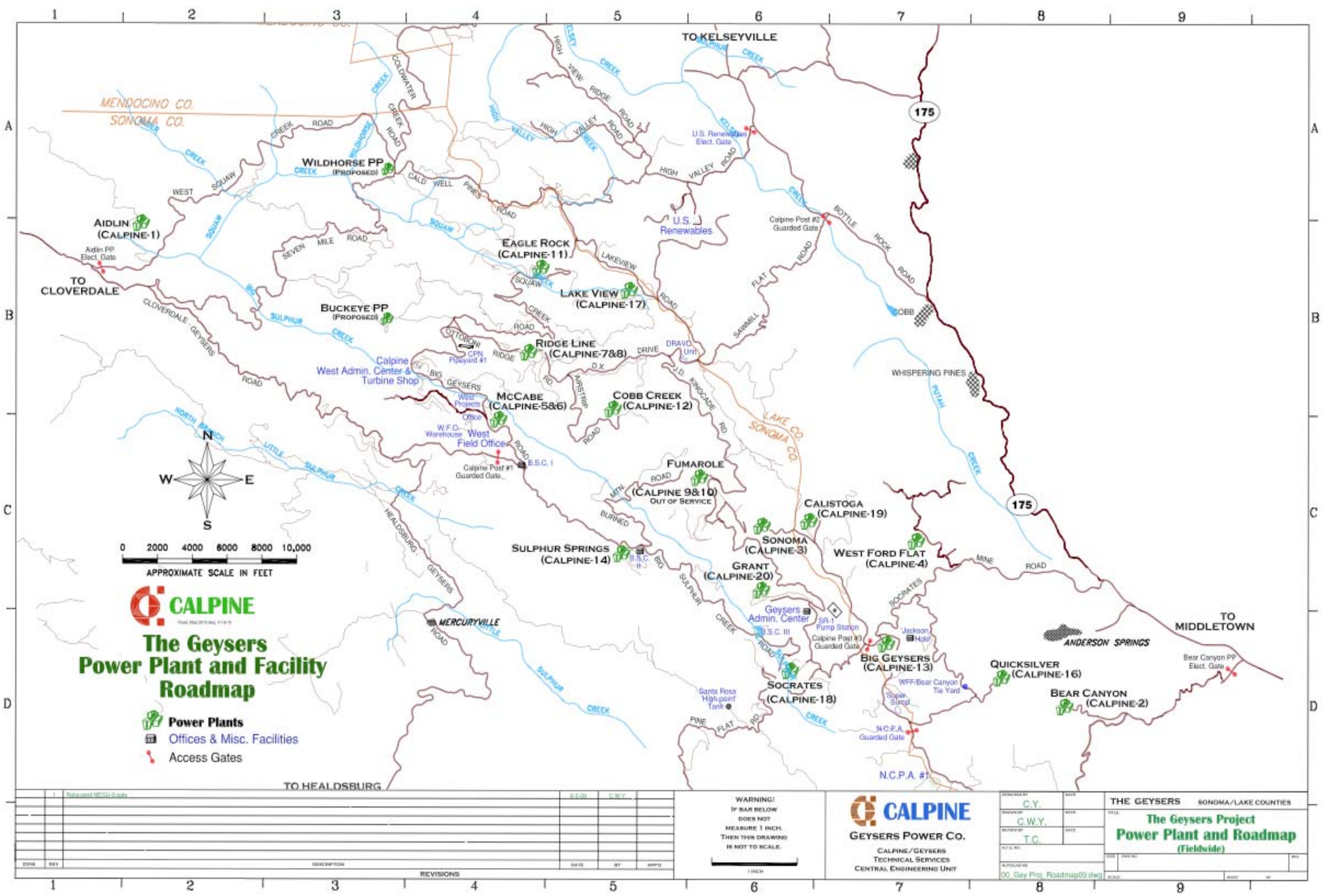
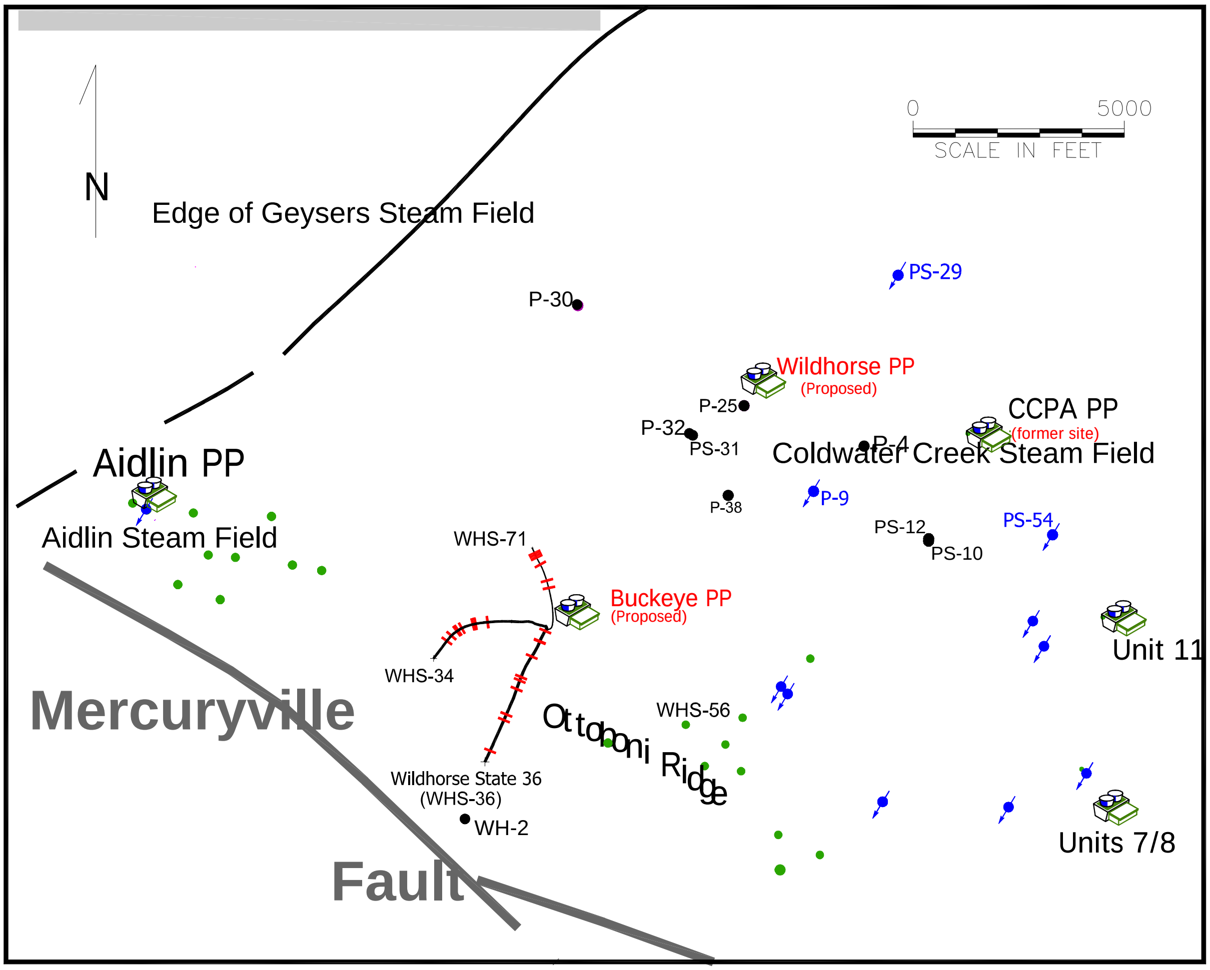


Figure 3 shows the well courses of the three wells drilled from the WHS-36 drilling pad and the steam entries (red bars) encountered along the WHS-36, WHS-71 and WHS-34 well courses.

Figure 3: Site Location Map Showing Well Courses and Surrounding Steam Fields



1.2 Purpose and Objectives

The purpose of the WHS-36 Confirmation Well Project was to characterize the reservoir production flow rates, temperature, pressure, thickness, permeability, and fluid chemistry of the prospective reservoir.

The project was also intended to test the hypothesis that steam production in the main portion of The Geysers field to the southeast might be geologically isolated from the Buckeye Power Plant area by intervening structural discontinuities in the subsurface. If this were the case, it was expected that reservoir pressures may not have significantly declined in the Buckeye area. If the WHS-36 confirmation well could demonstrate that the Buckeye Power Plant area reservoir exists in a "compartment" that is partially isolated from the main portion of the declined Geysers reservoir, it might be developed with minimum pressure interference to and from the surrounding steam fields.

An additional purpose of the project was to demonstrate that the injection of water into the high temperature zone in the Buckeye Power Plant area could create an Enhanced Geothermal System (EGS). The Buckeye Power Plant area is 3000′ to the northwest on Ottoboni Ridge where an EGS demonstration was proposed to the Department of Energy for construction in 2001 but never funded (DOSECC, Inc. and Calpine, 2001).

The specific objectives of the WHS-36 Confirmation Well Project were to drill, complete and test WHS-36, in order to provide data with which to characterize the production and economic viability of the resource. Data on noncondensible gas (NCG) concentrations in the steam produced by the WHS-36 confirmation well during the test stage were required to determine the proper size and operating costs of NCG handling equipment and hydrogen sulfide abatement systems for the proposed Buckeye Power Plant. Isotopic data collected from drill cuttings would assist in understanding the nature of the reservoir rock.

Specific objectives met by the project included the following:

1.2.1 Drilling and Completion

- *Drill WHS-36 to a depth of approximately 10,000 feet (′):* The well was completed at a total depth (TD) of 12,340′.
- *Set casing or production liner down to the top of the steam reservoir to stabilize unstable rock formations:* Cemented casing was set to 3177′. Slotted/blank production liner was set to TD. The top of steam was encountered at about 4669′ but was depleted to 9285′.
- *Case off ground water, lost circulation zones and condensation zones:* Lost circulation zones were encountered between 2687′ and 3188′. These were remedied with a series of six cement plugs. A water entry occurred at 6658′ in the depleted zone and is behind a production liner.
- *Collect and describe drill cuttings:* Cuttings were collected and described by Tecton Geologic.
- *Measure NCG concentrations while drilling and during bit trips:* NCG samples were collected while drilling and during bit trips.

1.2.2 Testing

- *Conduct isochronal flow testing to determine the deliverability, permeability and static pressure of the steam reservoir:* A three-day isochronal test was conducted between November 30 and December 4, 2010.
- *Collect at least four gas and condensate samples during the reservoir testing, and analyze for steam and gas constituents, including specialized analyses for chloride concentrations, to determine the likely characteristics of the produced steam:* Five samples were collected from the condensate and two downhole samples were collected for chloride and boron during testing. Twenty-six samples were analyzed for total NCG. One downhole sample was analyzed for major ion chemistry.
- *Log the flowing well to TD with a Pressure- Temperature Spinner (PTS) tool capable of withstanding temperatures to 600 degrees Fahrenheit (°F). Determine the flowing pressures, temperature and steam entry locations in the reservoir:* A PTS was run on February 16, 2010. Temperatures were also logged while drilling with Maximum Reading Thermometer (MTR).
- *Monitor pressures at the nearest static steam wells to determine if transient pressures produced by the steam testing program can be measured:* Pressures were monitored in WHS-34 and WHS-71.
- *Monitor hydrogen sulfide concentrations while logging and testing.* Hydrogen sulfide (H_2S) was routinely measured in the steam flow during air drilling per Northern Sonoma County Air Pollution Control District (NSCAPCD) air quality requirements.
- *Conduct static pressure monitoring that will continue for months following the reservoir testing program:* Static pressure was monitored continuously at a pressure gauge on the wellhead. Results are logged into Calpine's Production Information System.
- *Analyze selected drill cuttings from the reservoir for isotopic characteristics:* Drill cuttings were sent to Southern Methodist University for isotopic analysis.

1.3 Resource Area and Reservoir

The 1000-acre Buckeye Power Plant Area is delineated in published and publicly available exploration data. Ottoboni Ridge is part of an undeveloped 10 square mile area that was identified in a Public Interest Energy Research (PIER) Consultant Report as an area between the Aidlin and Ridgeline Power Plants (Units 7 and 8) that may "most likely" add 333 megawatts (MW) of generation at The Geysers (GeothermEx, 2004). Accordingly, the 1000-acre Buckeye Power Plant was thought to be capable of producing 52 MW of electrical generation from steam. The commercially productive Aidlin, Units 7 and 8, and Coldwater Creek steam fields, are each located about two miles distant from WHS-36.

The planned steam field area for the Buckeye Power Plant is within the much larger heat flow anomaly (≥8 Heat Flow Units) that defines the productive portion of The Geysers reservoir (Walters and Combs, 1992). The 1000-acre area was explored by eight temperature gradient holes and one deep exploration well, Wildhorse 2 (WH-2). One temperature gradient hole, WW-2, is 2010′deep and is located about 750′north of the WHS-36 wellhead. The temperature gradient in WW-2 is 7.3°F per 100 ′, and indicates that the top of the reservoir (460°F - 480°F) is about 5500 ′deep. Deep temperature gradient holes have been useful in predicting the approximate depth to the top of reservoir throughout the Northwest Geysers (NW Geysers).

The exploratory well, WH-2, located approximately 5000 'south of WHS-36, was drilled to a depth of 8044 'in 1968. WH-2 had a water entry at 3740 'and a water/steam entry at 4760 ' (presumably in the zone of condensation), and shows of steam beginning at 5730 'and 7630 '. Severe drilling problems (discussed below under Technical Considerations) resulted in termination of drilling. The well was not tested and could not be used as a confirmation well for the Buckeye Power Plant.

1.3.1 Evidence of "Compartmentalization"

Reservoir "compartments" in many oil and gas fields are created by structural discontinuities (faults and fracture zones) that cause pressure discontinuities between wells. There is evidence that reservoir compartments also exist at The Geysers, as in some other large geothermal fields (e.g. Coso). Pressures in the Buckeye Power Plant were hypothesized to be higher than the surrounding resource areas because of structural discontinuities believed to exist between the new power plant area and the main Geysers steam field to the southeast, and the Coldwater Creek steam field to the northeast.

The Aidlin steam field is adjacent to the proposed Buckeye Power Plant area and four miles northwest of the main Geysers steam field. The Aidlin steam field had higher initial temperatures and pressures [(>500°F and >600 pounds per square inch (psi)] than the initial conditions of the main Geysers reservoir (about 460°F and about 500 psi) (Hulen, et al, 2001). Pressures in the main Geysers reservoir declined from about 500 psi in the 1970's to about 200 psi by the early 1990's. The Aidlin steam field and other wells in the general area (e.g. Prati 30) show little evidence for a direct connection to the main Geysers reservoir. A proprietary field-wide reservoir model developed by Calpine indicates that a pressure discontinuity exists southeast of the proposed Buckeye Power Plant, and that this discontinuity or structural "membrane" is in the same approximate area as the Caldwell Ranch Fault (Figure 4) mapped by Neilson and others (1991).

Isotopic studies of the reservoir rocks in the Aidlin area and portions of Ottoboni Ridge show that this reservoir area evolved separately from the reservoir areas to the east and southeast (Walters and others, 1996). More recent studies show a positive correlation between the isotopically well-exchanged reservoir rocks in the Aidlin and Ottoboni Ridge areas and lower concentrations of NCGs in the Aidlin reservoir (≤2 percent by weight (percentwt)), in contrast to much higher NCG concentrations (6 percentwt to 7 percentwt) in steam from adjacent areas to the east and southeast (Walters and Beall, 2002; Beall and others, 2007). NCG concentrations of steam from wells on Ottoboni Ridge range from about 4.5 percentwt NCG in the southeast to ≤ 2 percentwt NCG in the Aidlin reservoir to the northwest.

Mapped faults and fracture zones (Nielson and others, 1991) may delineate distinctly different reservoir rock blocks with isotopically less-exchanged rocks from the isotopically more-exchanged rocks. The pressure data and reservoir modeling, isotopic and NCG data, and published fault and fracture mapping indicate that the Buckeye Power Plant reservoir may be part of a reservoir compartment partially isolated by geologic structural discontinuities, just as the Aidlin steam field is isolated from the steam reservoir to the east which contains high NCG concentrations, and from the pressure-depleted main Geysers steam field to the southeast.

1.3.2 Expected Geologic Conditions

The cap rock of the Buckeye Power Plant area reservoir consists of a greenstone complex to about 2200 ' depth, and metagraywacke and argillite to the top of the reservoir. The top of the reservoir was expected to be at a depth of approximately 5500 ′. Data from wells on Ottoboni Ridge to the southeast of WHS-36 indicate that at about 2800 ′ a greenstone mélange approximately 100 ′ thick would occur in the cap rock of WHS-36. Lost circulation zones and a possible water entry in WW-2 were encountered at depths of 540 ′, 750 ′, and 1645 ′, in a greenstone complex consisting primarily of greenstone and minor chert with intervals of graywacke.

The greenstone complex was encountered in all of the Aidlin wells to the northwest, as well as in the Ottoboni Ridge wells to the southeast. Reservoir rock in the Ottoboni Ridge wells to the southeast of WHS-36 consists primarily of very stable proximal to massive turbidites, typically consisting of 80 percent to 100 percent metagraywacke, and less than 20 percent interbedded argillite.

Slotted or perforated liners are typically not needed in the Ottoboni Ridge portion of the reservoir. The reservoir rocks found in the Aidlin wells northwest of WHS-36 are metagraywacke and argillite turbidites comprising thin-bedded units of 50 percent argillite and 50 percent metagraywacke that are characteristic of distal turbidites, and with unstable units of 100 percent argillite and mélange throughout the reservoir. Slotted liners are required in the Aidlin reservoir. The reservoir section expected in WHS-36, based on wells to the east of WHS-36 in the former Central California Power Agency (CCPA) steam field, was primarily metagraywacke, intercalated with one or two relatively thin argillite mélange sections.

Figures 4 and 5 show the geologic conditions expected in the WHS-36 area based on unpublished data collected by Mark Walters and others (DOSECC, Inc., 2001) Figure 4 shows the surface geology with cross-section A-A′ depicted as a geologic cross section in Figure 5. About 2200′of greenstone caprock and metagraywacke to final depth was expected.

Figure 4: Surface Geology in the WHS-36 Area

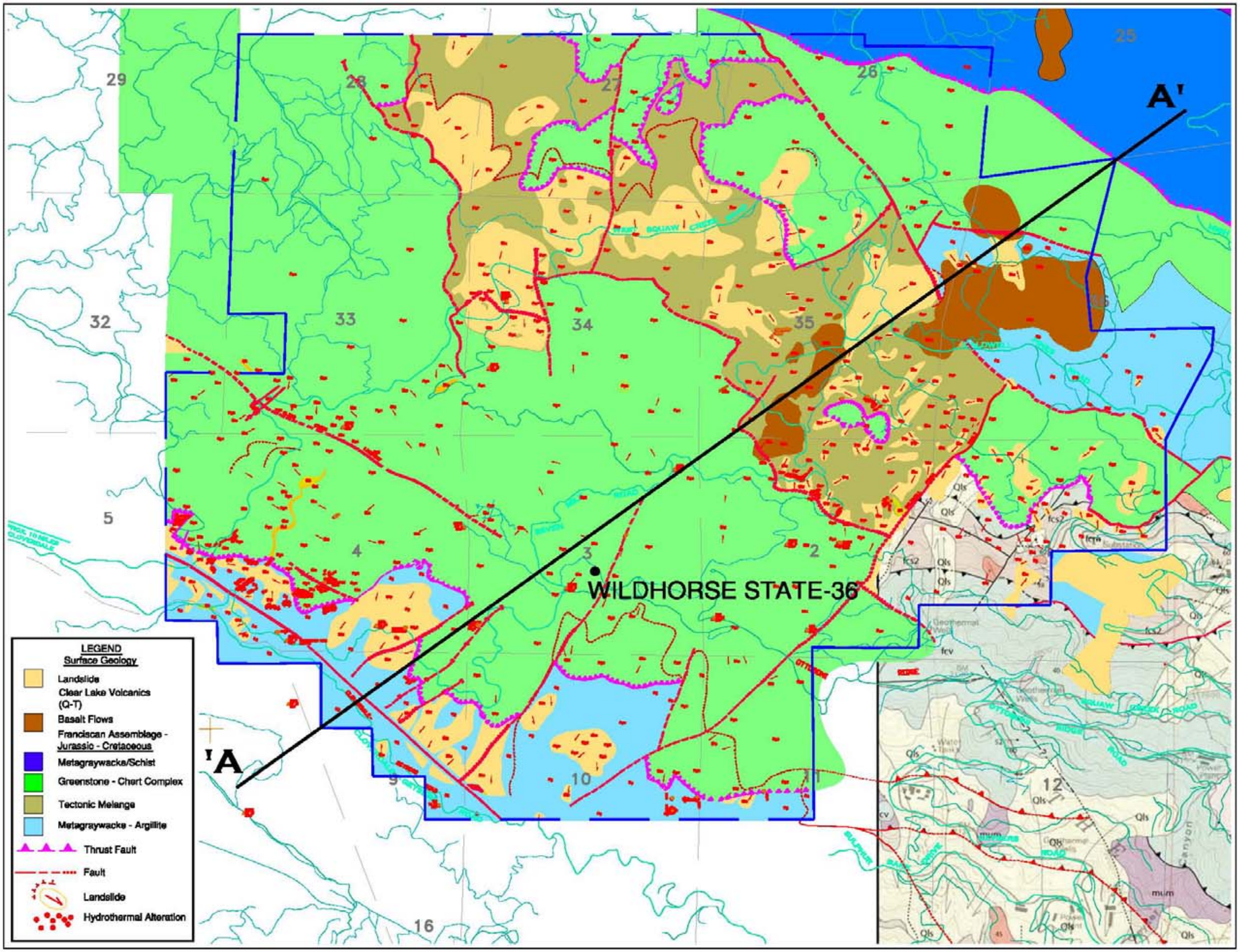
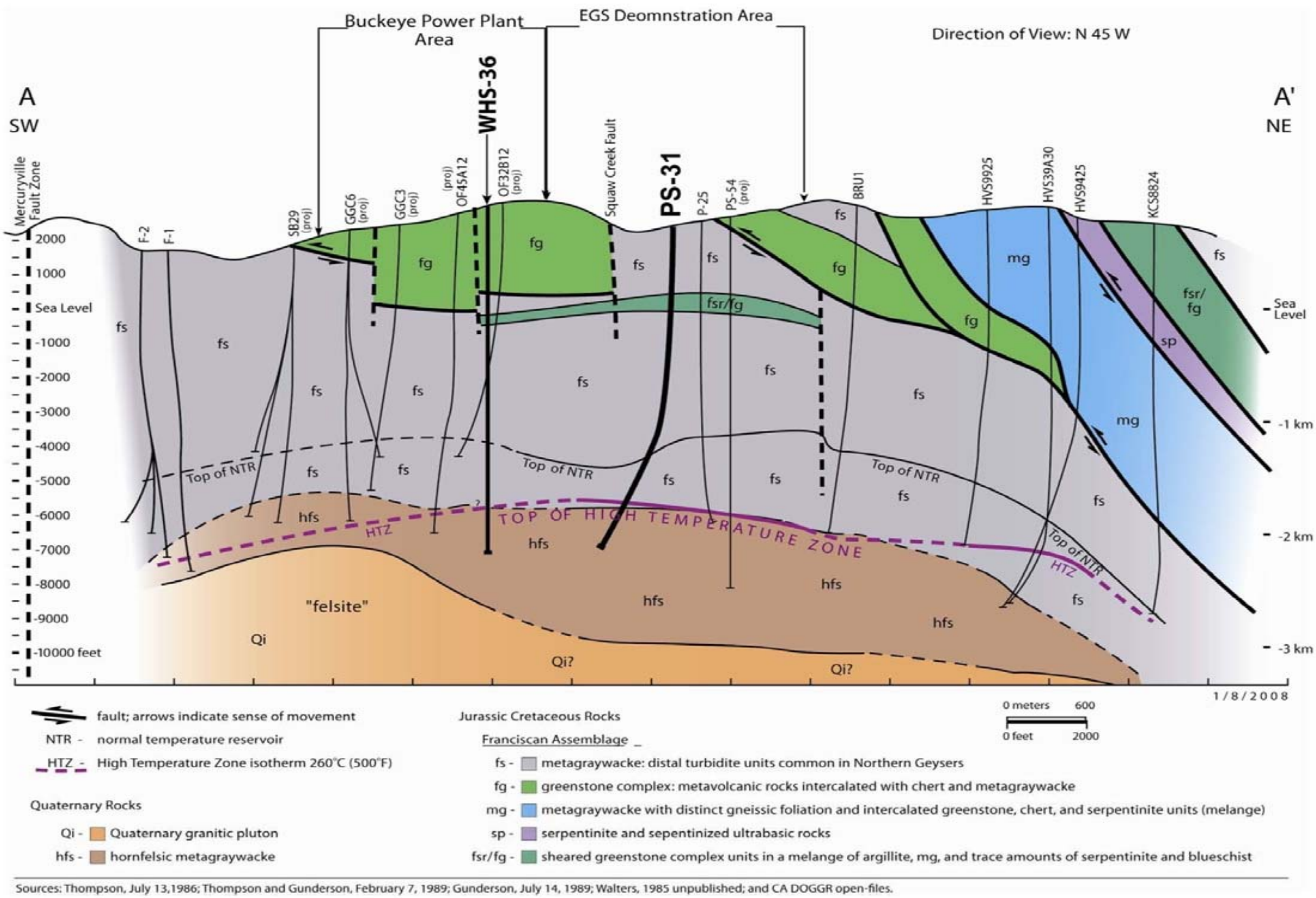


Figure 5: WHS-36 Geologic Cross Section A-A'



1.4 Technical Considerations

Much of the cost of drilling a geothermal well in the NW Geysers is related to the geology encountered in the reservoir cap rock. Lost circulation zones, water entries, and unstable mélange are present in the reservoir cap rock in the Aidlin wells to the northwest, and in the Ottoboni Ridge wells to the southeast of WHS-36. In all cases cement plugs were required to cure lost circulation zones prior to setting the production liner.

Exploratory well WH-2 had shows of steam beginning at 5730′ and 7630 ′. A water entry at 3740′and a water/steam entry at 4760 ′(presumably in the zone of condensation) indicated that the depth of the production casing, set at 3509 ′, was too shallow. Severe drilling problems created by an attempt at drilling with both mud and air below the water entries caused the original well bore to bridge, and the well was sidetracked from a depth of 3600 ′ to a total depth (TD) of 6845′. At 5500 ′, WH-2 Sidetrack 1 produced water during air drilling. Drilling of WH-2 Sidetrack 1 was terminated because of stuck drilling pipe and fill on connections, presumably caused by unstable formations in the presence of water. Prior to 1968, the unstable formations of argillite and mélange in the deeper portions of the NW Geysers reservoir had not been air drilled, and the need for deep production casing was not yet understood.

The drilling and completion objectives for WHS-36 were to prevent formation collapse by putting unstable cap rock behind cemented production liner set as close to the top of the reservoir as possible (about 5500 ′). The cap rock would be drilled with mud. Cement plugs and sidetracks were expected to be necessary prior to setting the cemented production liners. The decision for "calling the casing point", or depth at which to set the cemented production liner, was to be based on the appearance of competent graywacke with less than 15 percent to 20 percent argillite and no evidence of mélange, and below lost circulation zones, water entries (from the zone of condensation), and alteration mineralogy. Drilling data (rate of penetration, torque on the drill string, water losses or gain, and flowline temperature) would also be evaluated to determine the depth for setting the production liner in consultation with the mud logging geologist and the on-site drilling supervisor.

Slotted liner was prescribed for the entire reservoir section in order to prevent bridging of any argillite mélange formations and ensure that unstable formations would not affect well bore integrity in the reservoir section. Thus protected, it was anticipated that WHS-36 could be successfully tested and provide the necessary data to characterize the reservoir in the Buckeye Power Plant Area.

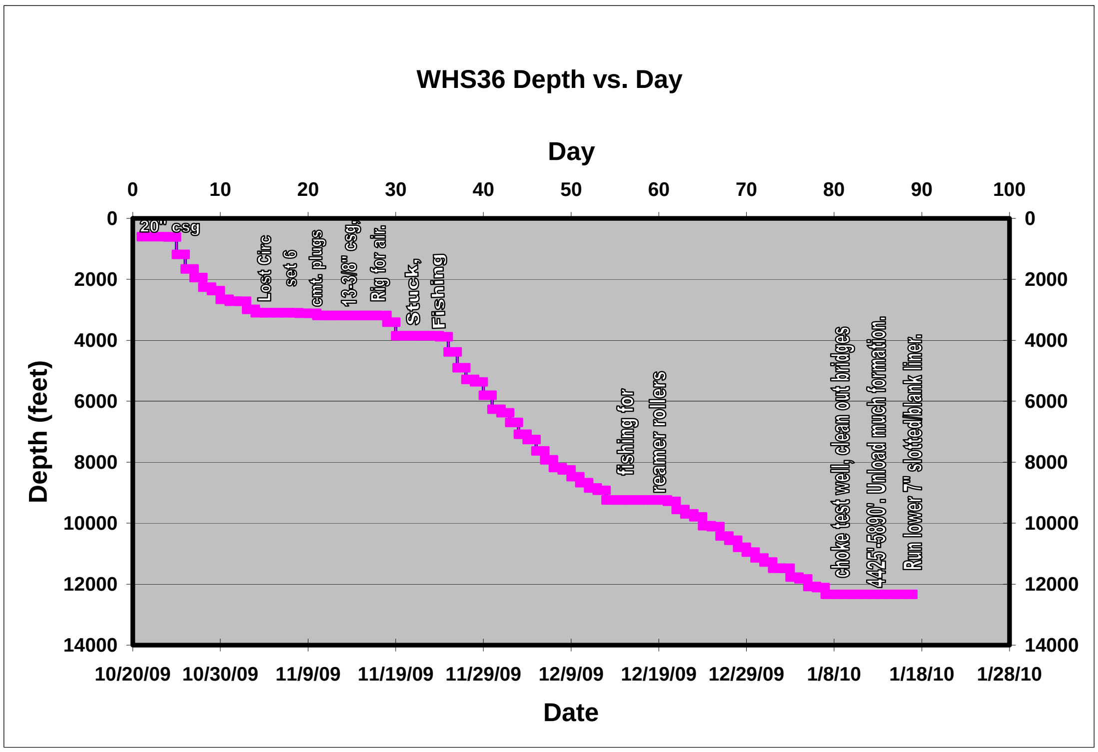
Calpine anticipated that bottom-hole temperatures in WHS-36 could reach 600°F. The testing tool selected for logging was Calpine's Pressure-Temperature-Spinner (PTS) tool, the Kuster Geothermal PTS, Model K10HTEMP, which is rated to 660°F for four hours, and 570°F for six hours. A Corona braided cable rated to 1500°F was selected for the logging line. The tool was to be run under the supervision of a highly experienced Calpine employee, increasing the likelihood of successfully logging WHS-36.

Calpine estimated that mobilization, drilling, logging, testing, and demobilization would take 59 days. TD was anticipated to be 10,000 ′.

CHAPTER 2:
Drilling and Completion History

Drilling of WHS-36 began on October 21, 2009. Figure 6 summarizes the progress of drilling. Major events are identified with annotations. Internal well reports are provided in Appendix A.

Figure 6: Drilling Chronology (Depth vs. Day)



The initial 26 inch (") hole was drilled with mud to a depth of 602'where 20" casing was cemented. A 17-1/2" hole was then drilled uneventfully to a depth of 2687' where loss of mud circulation began. Lost circulation problems increased in severity from 2687' to 3188'. The first of six cement plugs was set at 2687 '. The final cement plug was set at 3188 '. Thirteen and 3/8" casing was set at 3177'. The hole was reverse circulated to insure a good cement job. Mud returns to the surface were obtained throughout the cement job but no cement returns were observed. A 22-barrel (bbl) cement top job was required to bring the cement to the surface of the annulus between the 20" and 13-3/8" strings of casing.

From casing depth the hole was air drilled to 3853', where a plugged bit required pulling out of the hole. During the trip out of the hole, the drill string stuck. After determining a free point, operators were able to pull out all but 117'of the bottom-hole assembly. After picking up a fresh set of jars, the drill string was run back into the hole and screwed back into the bottom hole assembly. The bottom-hole assembly was pushed to bottom where it was worked free and the entire drill string recovered. A large amount of fill was produced from the bottom of the hole as it was cleaned out.

The hole then drilled smoothly from 3853‘to 4669′ without fill problems. At 4669′ a small entry of water/steam occurred. The well-produced large amounts of formation through a drilling break that extended from 4669‘to 4689‘. The entry produced a negligible amount of steam but raised the flowline temperature 30°F.

Drilling continued smoothly to a depth of 6588′, where another water/steam entry occurred. A wet test measured a flow of 14,300 pounds per hour (14.3 kilo pounds per hour (kph)) and the well began to produce water at about 10 barrels per hour (bph).

At 6651′, a wet steam entry increased the water production to about 15 bph. At 8258′, a steam entry raised the wet test flow rate to 32.4 kph and the well continued to produce about 15 bph of water.

The drill string stuck again at 9243′. The drill string was freed and pulled out of the hole and it determined that a reamer had lost its rollers. A seven-day period of milling and fishing was required to break up the rollers and retrieve the pieces. When drilling resumed a cluster of steam entries were recorded at 9285′, 9311′, 9336′, and 9483′. This group of entries did not result in steam flow increases as measured by wet tests. Following these steam entries, water production declined to about 10 bph. Either in conjunction with, or just prior to an entry at 10,783′, the well ceased to make water. A total of 11 steam entries were encountered from 4,669' to 11,967'.

A maximum reading thermometer (MRT) was run with the directional tool inside the drill pipe at 10,749′. This was the deepest MRT reading obtained, and recorded a temperature of 624°F. Additional steam entries were observed at 10,970′ and 11,967′. Drilling was terminated at a TD of 12,340′ on January 7, 2010.

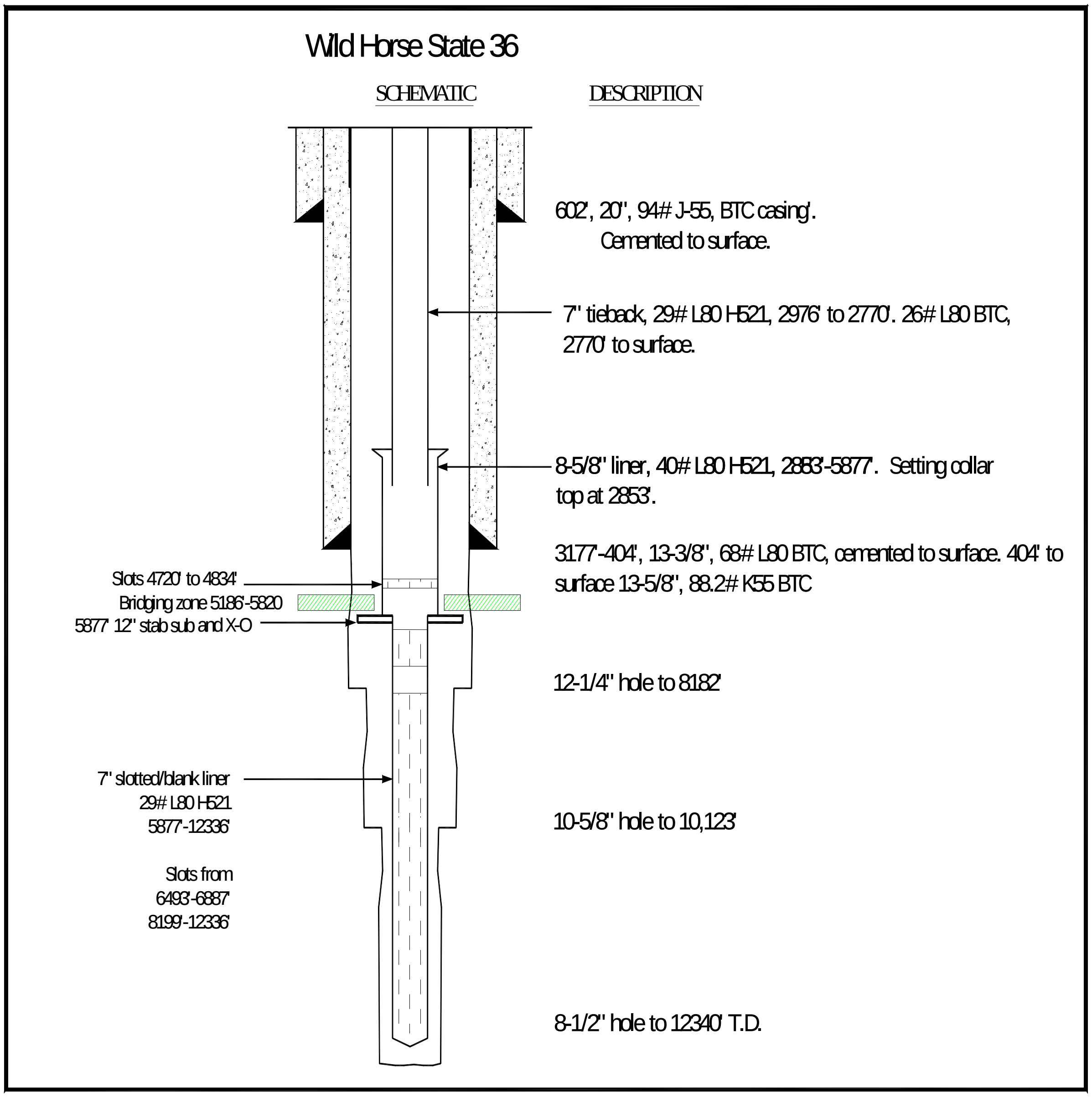
Below 9000′ the hole angle, measured from vertical, climbed rapidly from about 35° to over 48°, causing the well trajectory to move rapidly to the south-southwest. Weight was taken off the bit in an attempt to decrease the hole angle, with no significant effect. The bottom hole location is 3470′ S25°W from the wellhead.

On January 8, 2010, a brief shut-in of 2.5 hours was followed by a 3.5″ choke test. The well flowed at 43.8 kph with an upstream orifice pressure of 91.4 pound-force per square inch gauge (psig) and a wellhead temperature of 329°F. This is equivalent to a flow rate of 43 kph normalized at a 100 psig wellhead pressure (WHP). A WHP of 208 psig was measured after five hours of shut-in. A Horner plot of these data provided a reservoir pressure of 303 psig.

After the preliminary testing several unsuccessful "wiper runs" were attempted to ensure that the hole was open to TD. The initial wiper run attempt encountered a bridge at 5816′-5820′. A massive amount of formation was unloaded from the well while the bridge was being cleaned out, causing the flowline muffler to plug. Subsequent wiper run attempts encountered bridges at 4425′, 5186′, 5800′-5829′ and 5885′-5890′. The produced formation caused the muffler to plug several more times. Deep bridges were encountered at 10073′ and 11409′ and were also cleaned out. These bridges were probably sloughed material that had fallen down the hole. The final wiper trip to TD encountered a bridge at 5826′ and the hole was unobstructed from that depth to TD.

On January 16, 2010 a combination 8-5/8” and 7” liner was installed. WHS-36 was completed on January 21, 2010 at a TD of 12,349’. Figure 7 is a schematic of the well.

Figure 7: WHS-36 Well Schematic



A final wet test flow rate was calculated at 47.8 kph. Visual and wet test estimates of well flow during this period confirmed that the well was not flowing at “full strength”.

After a period of shut-in the well was choke tested again on February 16-17, 2010. With the liner installed in the well and a 3” choke in the flow line, a flow of 34.1 kph was measured with an upstream orifice pressure of 98.3 psig. This is equivalent to a flow rate of 37 kph normalized at 100 psig WHP, and suggests a loss of six kph caused mainly by the installation of the 7” liner.

2.1 Breakthrough from WHS-71 and Subsequent WHS-36 Work Over

During the choke test in February, WHS-71 was being drilled with mud from the same drill pad as WHS-36. WHS-71 had reached a depth of about 3500′, when significant circulation loss occurred. Drilling mud began flowing from the WHS-36 test muffler during a downhole sampler (DHS) logging run that was being conducted at the time. During the surface chemical sampling of WHS-36 it was noted that drilling mud was also flowing from the wing valve. Because the drilling in WHS-71 was taking place below the 13-3/8″ casing depth of 3177′, it was apparent that drilling mud from WHS-71 was breaking through to the WHS-36 well bore.

Three downhole NCG samples were collected on February 17, 2010. Subsequently, mud cuttings from WHS-71 filled up the muffler at WHS-36. The well was then shut-in and vented several times with and without outside air in an effort to clean the wellbore. On February 26, 2010 a wet test indicated a flow rate of 15 kph at a WHP of 76 psig. On March 9, 2010 a PT traverse run was attempted but the instrument could not go below 6,835′ apparently due to blockage in the wellbore. A downhole camera run on April 20, 2010 confirmed this.

WHS-36 was reentered to clean out the obstructed well bore and repair the apparent loss of productivity associated with the breakthrough of mud from WHS-71. On May 23, 2010, WHS-36 was reentered with tools to "spear" and pull the upper 7″ hang down liner. After retrieving the upper liner, the lower liner was entered with a 6″ bit and 3-1/2″ drill pipe. At 4500′ a wet test recorded only 23.3 kph. At 6873′, the drill string "tagged up". After light reaming and blowing the well allowed progress to 6944′. At that point the drill string was pulled from the well, the bit was removed, and the drill string was returned open-ended into the well. At 8785′ the hole tightened around the drill string, probably because the lower liner segment was set on bottom and was in compression. The pipe was pulled up to 2378′. A wet test then measured a flow rate of 47.8 kph. With full flow apparently recovered, the drill pipe was pulled from the well and the upper, 7″ liner was rerun and stabbed 114′ into the lower liner.

After a period of well testing described below, WHS-36 was pressured up with compressed air seven times (see Appendix A, Air Up Report). The intent was to depress the water level, allowing the water to heat up, then release the pressure, causing the water level to rebound, flash and thereby clear the well bore of water. Seven pumping episodes of one hour each, injecting 72,000 standard cubic feet of air, raised wellhead pressures from 340-360 psig to a final pressure of 370 psig in each case. No water was purged from the well through this effort.

After WHS-36 was pressured up, apparently the air bled off to the formation above the standing water level. Very high nitrogen content in NCG samples taken from WHS-34 corroborates this possibility. A WHS-34 NCG sample taken on December 10, 2010 had a concentration of over 1600 parts per million by weight (ppmw) nitrogen (N_2) out of a total NCG concentration of about 4000 ppmw. This extraordinarily high N_2 concentration constituted almost 40 percent of the NCG by volume in that sample. NCG samples taken from WHS-36 on December 3, 2010 also had extremely high N_2, both in terms of ppmw and volume percentage of the total NCG. It is clear that the three wells, WHS-36, WHS-34 and WHS-71, communicate fairly directly. The mud breakthrough episode from WHS-71 to WHS-36 took place at shallow depth, when WHS-71 was drilling at about 3500′. At shallow depths all of these wellbores are relatively close together, facilitating subsurface communication.

2.2 Mud Logging

Figure 8 summarizes the drilling, geology, and steam entries encountered in WHS-36 during drilling. The complete mud log produced by Tecton Geologic is included in Appendix B.

CHAPTER 3: Testing

A chronology of testing and testing results is included in Appendix A.

3.1 Short Term Rig Tests (Choke Tests)

Three short term rig tests were performed on WHS-36. On January 8, 2010, after reaching TD, a brief shut-in of 2.5 hours was followed by a 3.5″ choke test. The well flowed at 43.8 kph with an upstream orifice pressure of 91.4 psig and a wellhead temperature (WHT) of 329°F. This is equivalent to a flow rate of 43 kph normalized at 100 psig WHP.

On February 16 and 17, 2010, after cleaning out the well, installing the liners, and a period of shut-in, a flow test was again conducted using a 3″ choke. The well flowed at 36.1 kph with an upstream orifice pressure of 105.4 psig and a WHT of 334.2°F. This is equivalent to a flow rate of 37.3 kph normalized at 100 psig WHP. The temperature probe was located close to the pipe wall during this test.

WHS-36 was choke tested for a third time on June 14, 2010 after the work over. This flow test was conducted for 4.75 hours using a 3.5″ choke. Figure 9 presents the results of the June 14, 2010 test. The well flowed 32.8 kph at a WHP of 63.8 psig and a WHT of 312.8°F. Tecton Geologic consultants were able to run a temperature probe close to the center of the blooie line to get an accurate temperature reading. In contrast to earlier tests, a superheat (SH) of 3.3°F was measured. The flow rate normalized at 100 psig WHP was 31.1 kph.

Figure 8: WHS-36 Drilling and Geologic Summary

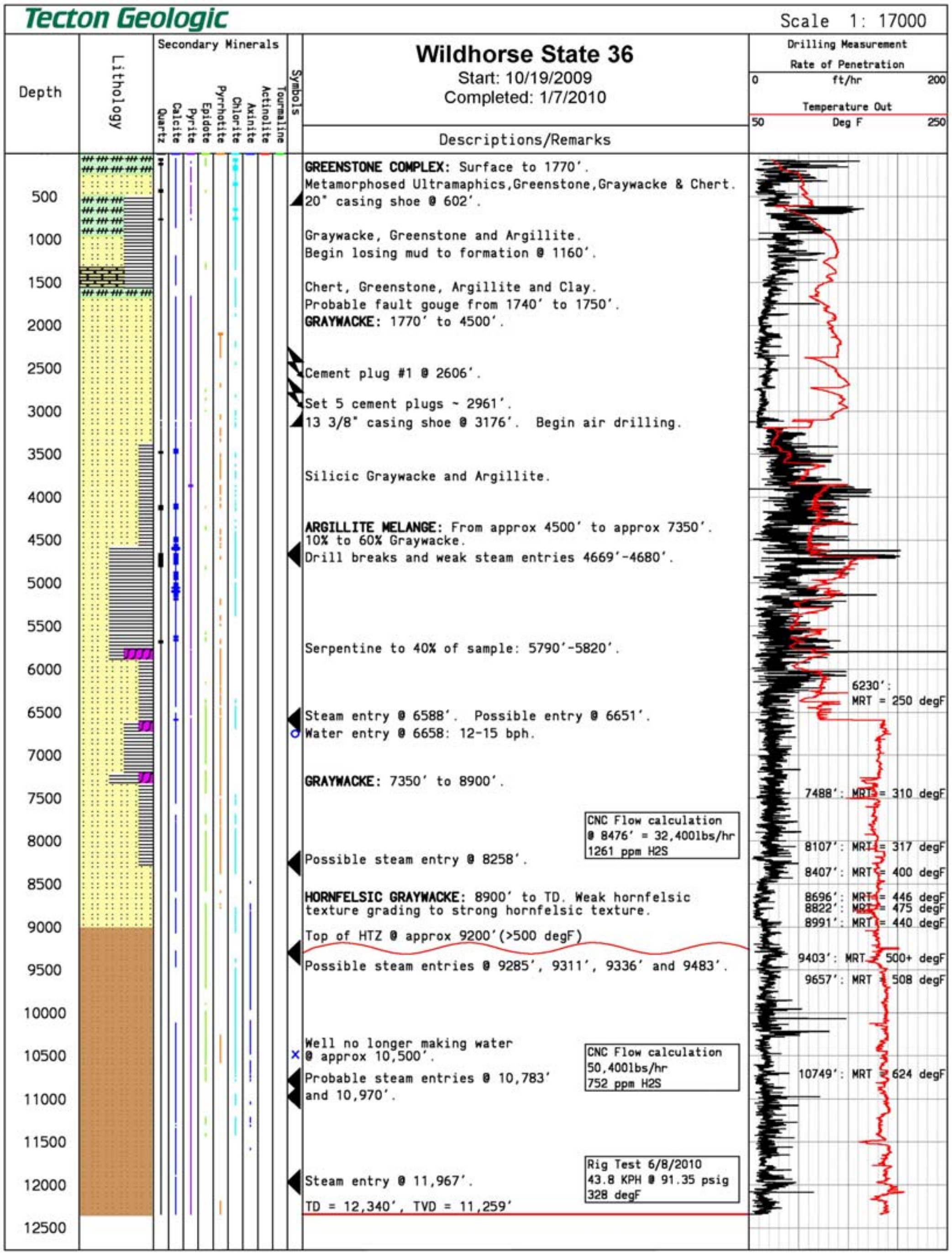
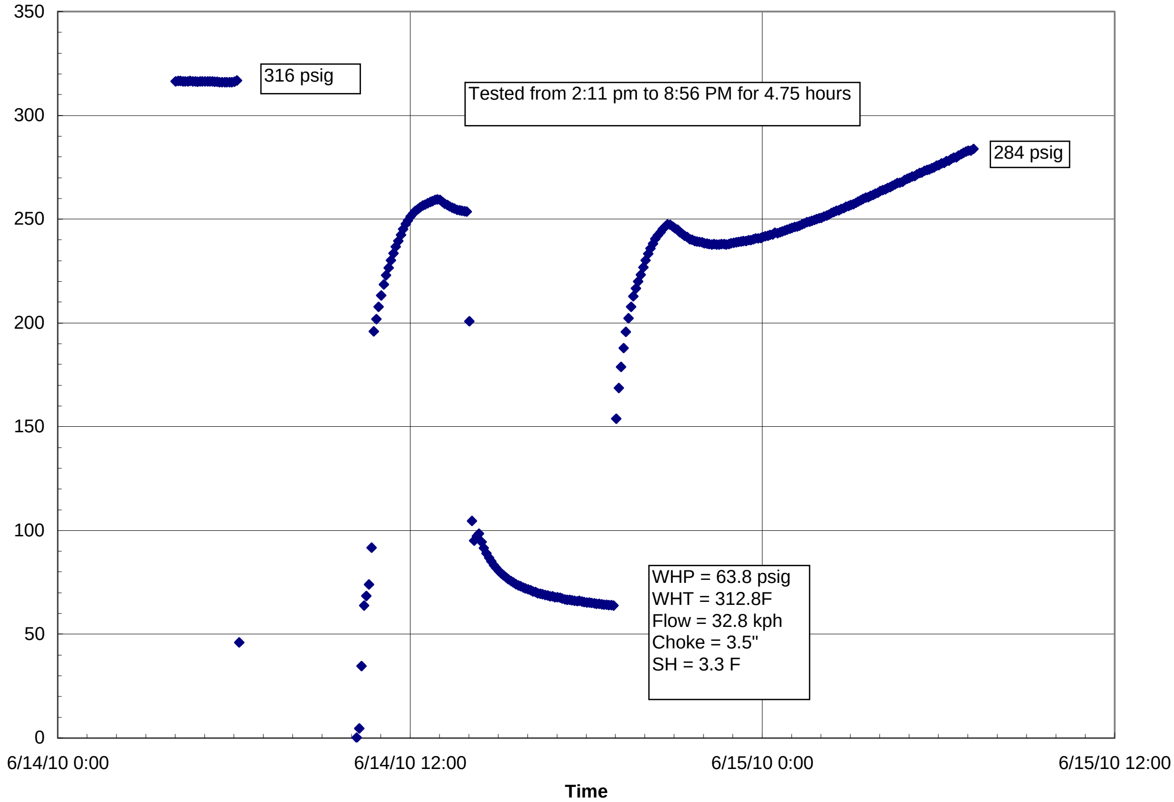


Figure 9: Short Term Rig Test (6/14/10)



3.2 Pressure - Temperature - Spinner Logging

On February 16, 2010, a pressure-temperature-spinner (PTS) log was run in preparation for taking downhole samples. The PTS survey was run from 3,100′ to 11,675′ at 50 feet per minute (fpm). Maximum temperature and pressure of 532°F and 220 psig were measured at 10,500′. The temperature portion of the log is shown in Figure 10, along with a temperature log obtained using a mechanical Kuster tool on March 9, 2010. The March 9, 2010 temperature log was unable to get below an obstruction at a depth of about 6840′, presumably because of the mud breakthrough described above.

Figure 10: Temperature Logs (2/16/10 and 3/9/10)

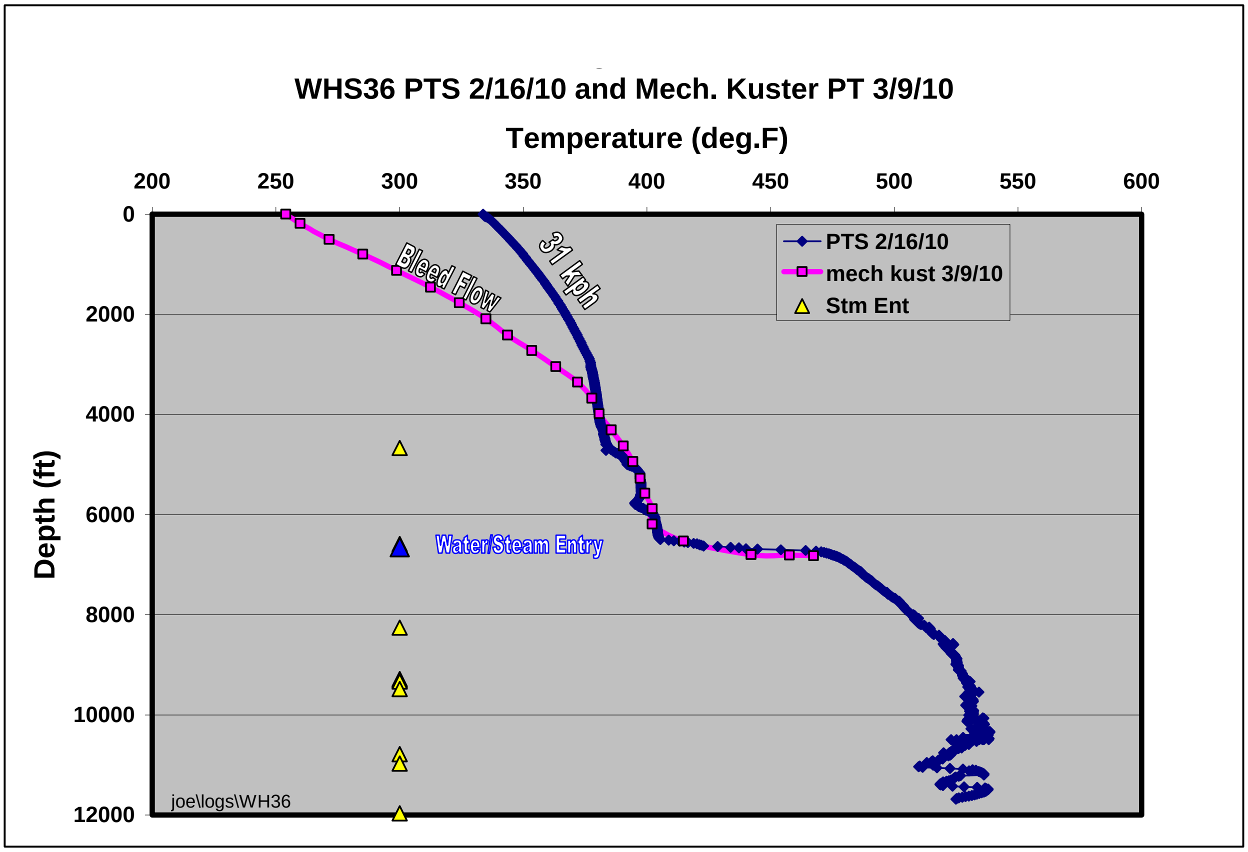
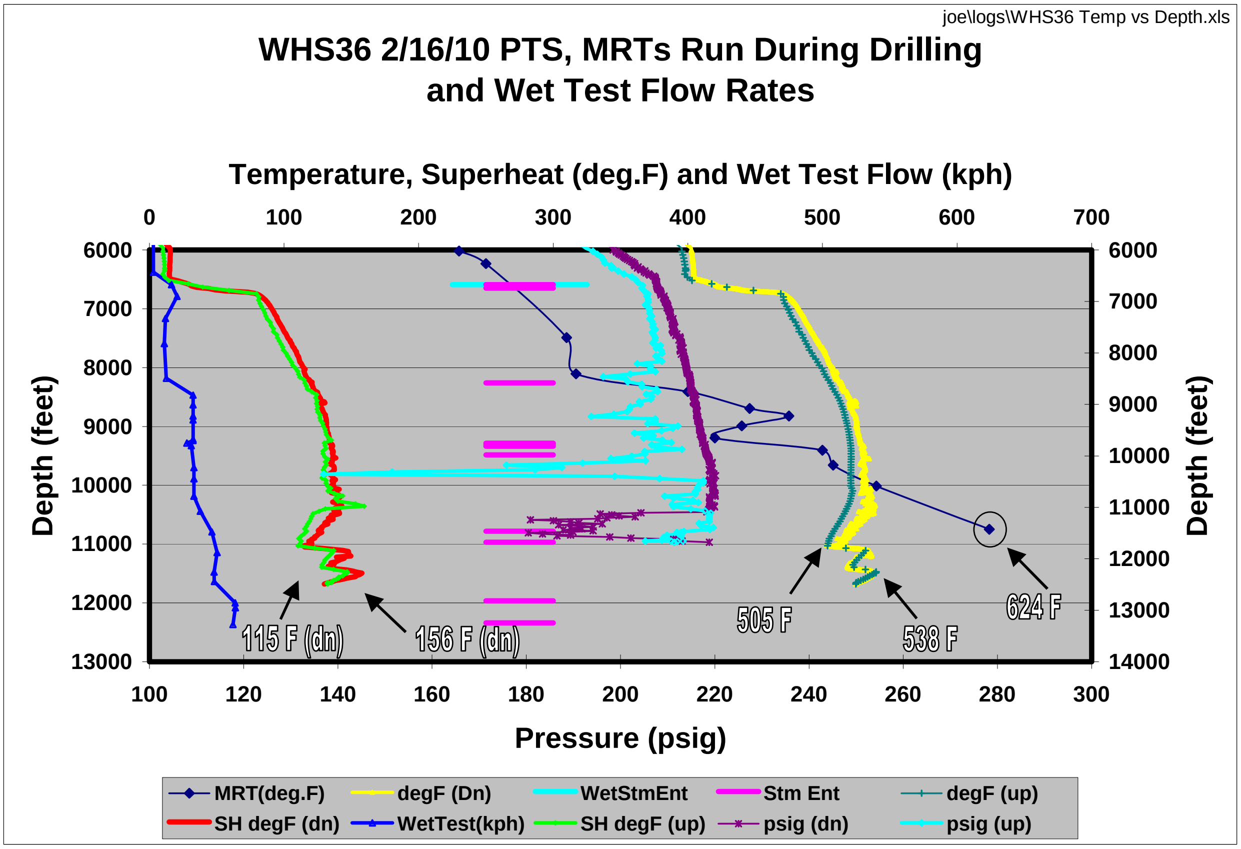


Figure 11 shows results from testing conducted on February 16, 2010 including the temperature log down and up, pressure log down and up, SH down and up, wet test flow rates, and the temperatures recorded by a maximum reading thermometer (MRT) run in the drill pipe with the directional tools during drilling before tripping for bits.

Figure 11: PTS Log (2/16/10), MRTs and Wet Test Flow Rates



3.2.1 Analysis

The February 16, 2010 temperature log (Figure 10) clearly shows the influence of the wet steam entry at 6588′ as the temperature drops abruptly from about 475°F to 405°F. The February 16 and March 19, 2010 logs are in very close agreement up to a depth of 3700′ in spite of the fact that the February 16, 2010 log was recorded with the well flowing at 31 kph, while the March 9, 2010 Kuster log was recorded at bleed flow. This indicates that at the time of the Kuster logging on March 9, 2010, the well was still flowing from the hotter entries below 6830′, presumably through the 12-1/4″ x 7″ annulus. The log also indicates the presence of a "thief zone" at about the depth at which the two logs diverge (3700′). At this point steam is leaving the well bore, possibly at the point of breakthrough from WHS-71, which was drilling at 3500′ at the time. Highly superheated steam (80°-150° of SH) is being produced below the wet steam entry at 6651′.

Some anomalies are present in the data presented in Figure 11. The temperatures logged down and up show a maximum slightly below 10,000′ (538°F on the down log). A reversal (decrease) in temperature is indicated from that depth to 11,000′ (where the temperature is 505°F on both the down and up logs). Two smaller scale increases and reversals appear between 11,000′ and the end of the log at 11,638′. The temperature logs down and up are in close agreement, indicating that the data are good. Fluctuations in temperature of this magnitude at depth are difficult to explain and probably indicate that the wellbore is approaching the Mercuryville Fault, which marks the southwestern edge of the reservoir in this area (Figure 3). The WHS-36 wellbore may be reacting to the colder temperatures at depth to the southwest of the fault.

Another anomaly in Figure 11 is the final MRT temperature recorded as 624°F at 10,749′. This temperature is far higher than measured by the PTS tool at that depth. A possible explanation for the higher MRT reading is that a cooler entry (or entries) took place below the MRT reading at 10,749′. A saturated steam entry may have occurred between 10,749′ and the total measured depth of the well (12,340′). The erratic pressure behavior in this depth range may also be an indication of flashing in the wellbore. The pressure in the log up is quite erratic over much of its range.

3.3 Static Pressure - Temperature Testing

Figure 12 shows the results of the static pressure-temperature (PT) log run on November 15, 2010, after several months of shut-in. This static PT survey was run from surface to 10,800′. The survey suggested a boiling water level below 9,500′ drowning all three steam entries (9 psi) encountered below this depth. Attempts were made to unload this water on November 28 and 29, 2010 by injecting air to a pressure of 370 psig, but failed (Table 2 in Appendix A).

Figure 13 shows the final static pressure and temperature log run on December 8, 2010. Steam entries (shown in red on the figures below) at 6588′ and 6651′ were wet. During drilling, the well made about 15 bph of water after these entries, but dried up at or slightly before the steam entry at 10,783′.

Figure 12: Static Pressure-Temperature (P-T) Traverse Log (11/15/2010)

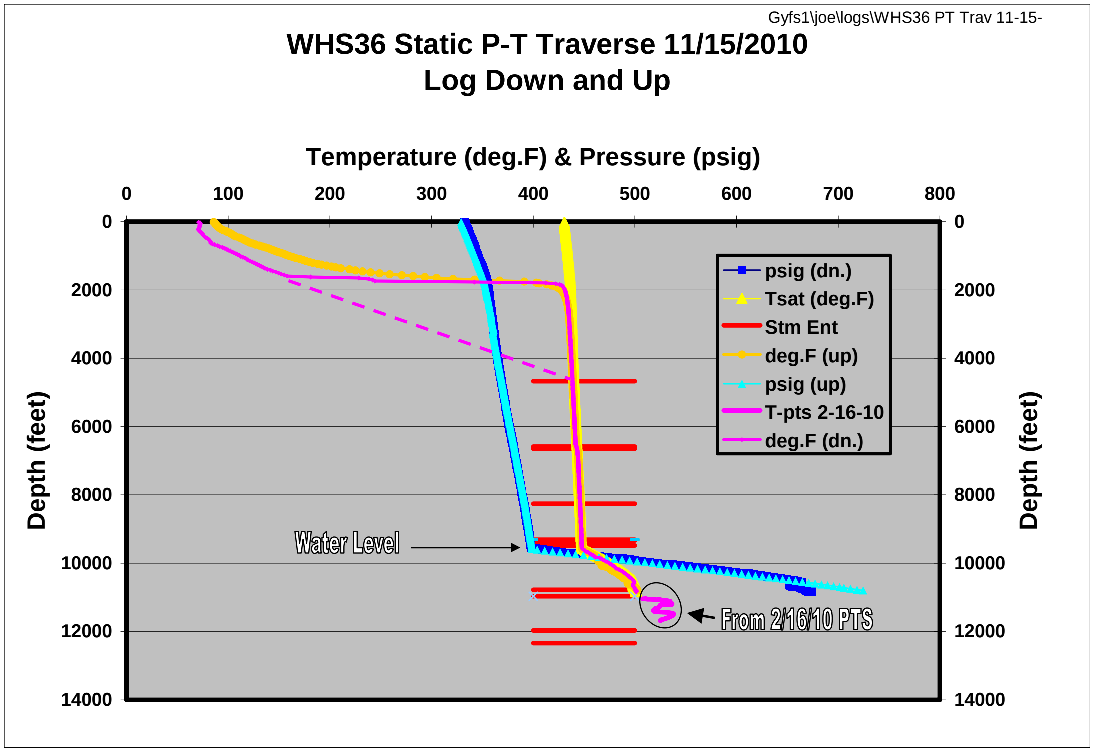
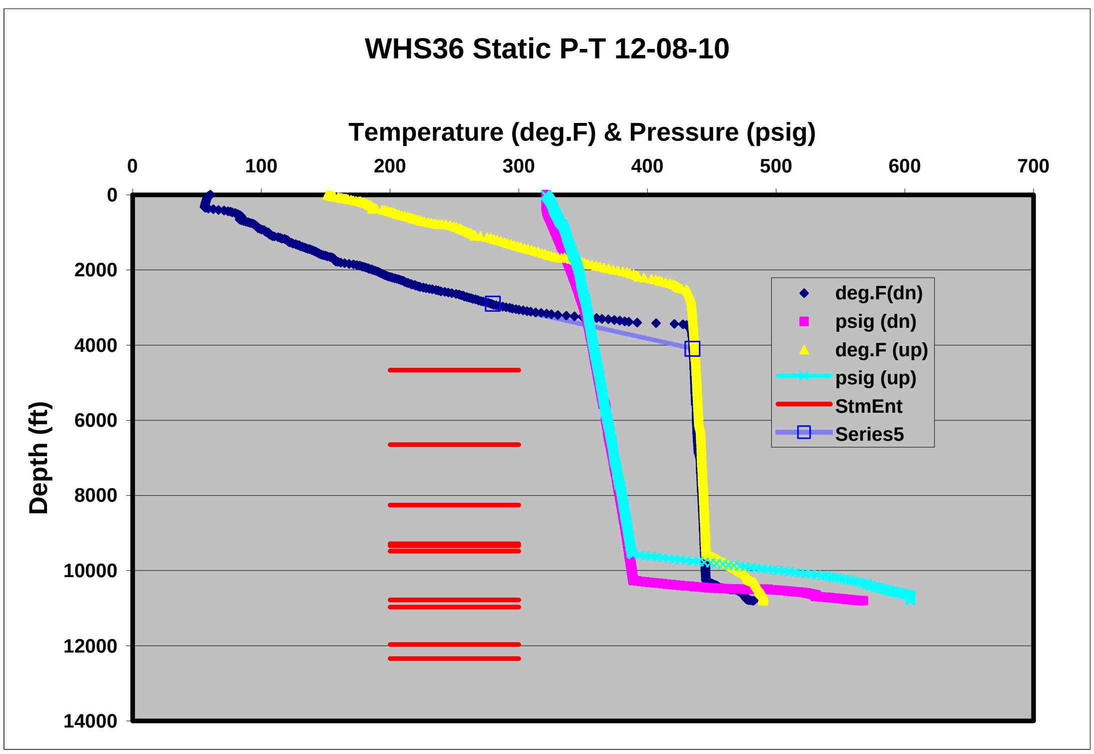


Figure 13: Static Pressure - Temperature (P-T) (12/08/10)



3.3.1 Analysis

Both the temperature and pressure measurements are in very good agreement on the down and up portions of the November 15, 2010 PT log (except for the last part of the up log), indicating excellent data quality. The maximum depth of the survey was 10,800′. A short piece of the February 16, 2010 PTS temperature log from 10,800′ to 11,680′ (Figure 11) "splices" on to Figure 12 reasonably well.

Unlike the previous logs, the November 15, 2010 log indicates that the hole had developed a standing water level at about 9500′. The pressure gradient below the water level indicates a column substantially lightened by boiling. Previously, the well-produced steam with 115°F to 140° F SH from below 8000′. It was postulated that water flow from the wet entries at 6588′ and 6651′ filled the hole with water to 9500′, with permeability below that depth damaged by the mud breakthrough event. Alternatively, it is possible that as the well bore approached the Mercuryville Fault at depths near TD, a saturated entry may have been encountered. A cooler, two phase flow may have subsequently developed, flowing to the thief zone at about 3500′, eventually establishing a boiling water column in the well bore. Subsequent analysis of major ion chemistry (discussed below) confirmed the latter hypothesis.

The well bore is nearly isothermal, and is at saturation temperature from 2000′ to 9700′. The temperature decreases about 17°F over an interval of 7700′. The extraordinarily high temperature gradient immediately above 2000′ must represent a transient or non-equilibrium condition. Normally the sharp break in slope of the temperature profile is controlled by the steam-gas interface in the well. A gas cap of NCG (primarily carbon dioxide (CO_2)) forms at the top of the well bore and pushes the steam downhole to a depth at which temperatures are sufficiently high to allow saturated steam to form. It is not clear why the temperature remains at saturation to such a high level in this log. The dashed line on Figure 12 represents the “expected” temperature profile through this interval.

In several respects, the December 8, 2010 log is similar to the November 15, 2010 log. A deep water level is indicated and a long, nearly isothermal section of well bore is observed above the water level. In the December 8, 2010 log, there is clear evidence that the deep water level moved upward during the logging from about 10,300′ to 9400′. During a 15-minute stop at 10,802′, (the greatest depth reached), the pressure increased 35 psig, indicating a rising water level. The divergent temperatures in the shallow regions of the down and up logs indicate some “leak by” of wellbore gas and steam profiles (the dark blue and yellow lines do not overlay). Minor leakage through the lubricator during the logging may have allowed steam to migrate up hole.

3.4 Three-Day Isochronal Test

A three-day isochronal test was conducted from November 30 to December 4, 2010, using 4″ and 5″ orifices. The test was started with an orifice of 4″ and choke of 2″. The well-produced saturated steam for eight hours. The pressure differential created by the steam flow through the 4″ orifice was out of the range of the transmitter, so a 5″ orifice was used for the rest of the test. Data from the test are shown in Figure 14.

Duplicate readings for pressure, temperature and differential pressure (DP) point were taken using Calpine and Tecton transmitters. These readings were quite similar as shown on Figure 14, suggesting all instruments worked well. The pressure and flow rate data of three eight-hour tests are plotted in Figure 15. The slope of the line in this figure provides a value of 1.1173 for the exponent "n". At the end of 24 hours flow, WHS-36 produced 27 kph of saturated steam at 79 psig and 320°F. This is equivalent to 26 kph normalized at 100 psig. This flow rate is lower than 31 kph, which was calculated on June 14, 2010 from the choke test.

Figure 14: Isochronal Test (11/30/2010 to 12/4/2010)

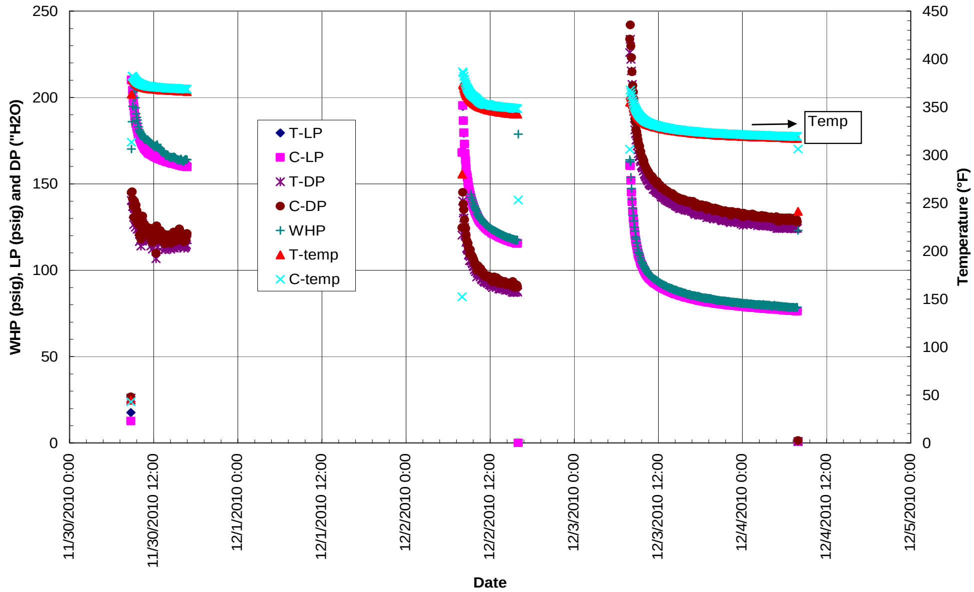
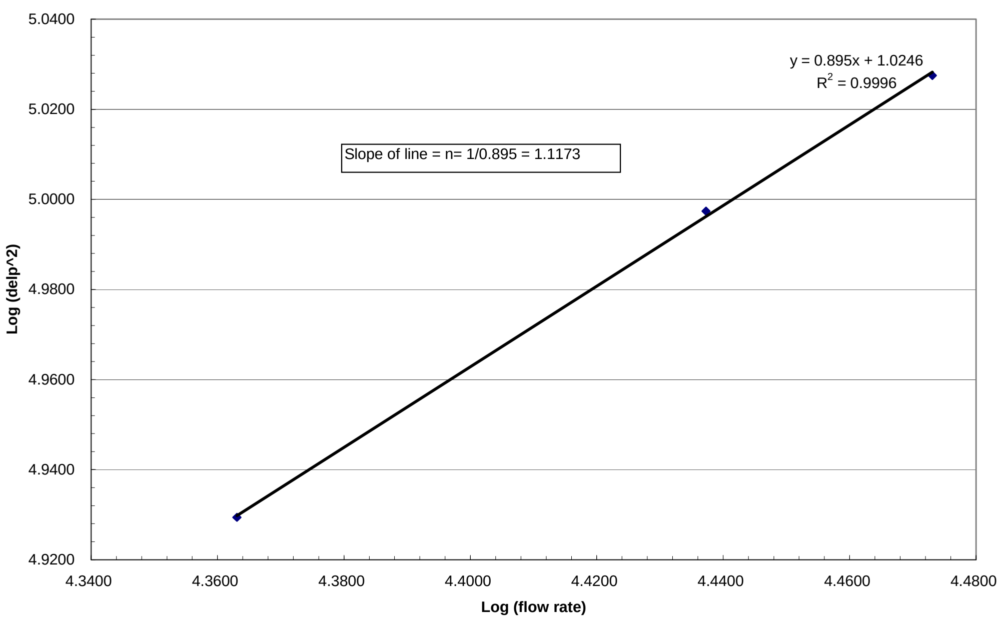


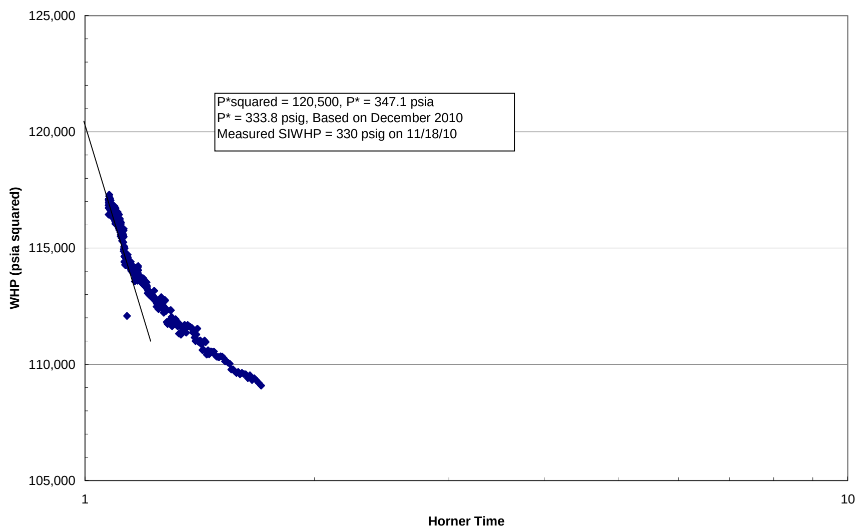
Figure 15: WHS-36 Orifice Isochronal Test



3.4.1 Analysis

The pressure buildup data after the isochronal test are reproduced on a Horner plot presented in Figure 16. This plot suggests a maximum shut-in WHP (P*) value of 334 psig.

Figure 16: Horner Plot



3.5 Pressure Monitoring at Nearby Static Steam Wells

WHS-36 is in pressure communication with both nearby wells WHS-34 and WHS-71 as indicated in Figures 17 through 19. This communication was further confirmed by high nitrogen levels in a WHS-34 gas sample on December 12, 2010 and appearance of mud in the WHS-36 muffler from WHS-71 drilling on February 17, 2010.

Instead of using data loggers to collect pressure interference data, Calpine's Production Information System (PI) data were used. WHS-34 data were available on PI. However, WHS-71 continues to remain disconnected from PI due to unavailability of 500 psig pressure transmitters. The WHP data of WHS-34, obtained from PI during the isochronal test, are shown in Figure 17. These data show a cyclic variation of approximately 1 psi. No clear interference is visible in this figure while the overall trend shows a drop in the WHP.

A data logger was installed on WHS-36 during the isochronal test of WHS-34 from December 7 to December 10, 2010. That data, shown in Figure 18, clearly identifies pressure interference between WHS-36 and WHS-34. The high nitrogen content in the gas sample collected from WHS-34 on December 10, 2010 also supports communication between WHS-36 and WHS-34. Similarly, shut-in well head pressure (SIWHP) data from WHS-71 were also collected during a five-hour test of WHS-36 on June 14, 2010, as presented in Figure 19. These data suggest pressure interference between WHS-36 and WHS-71.

During the WHS-36 flow test conducted on June 14, 2010, the WHP data at the nearby well WHS-71 was collected. WHS-71 exhibited a pressure drop of 0.3 psi as shown in Figure 19.

Pressure data recorded at WHS-36 during the isochronal test of WHS-34 from December 7-10, 2010 clearly identifies pressure interference between WHS-36 and WHS-34 (Appendix A, WHS-36: Isochronal Test November 30 to December 4, 2010). In short, both nearby wells WHS-34 and WHS-71 interfere with WHS-36.

Figure 17: Pressure Interference in WHS-36 due to WHS-34 Flow Test

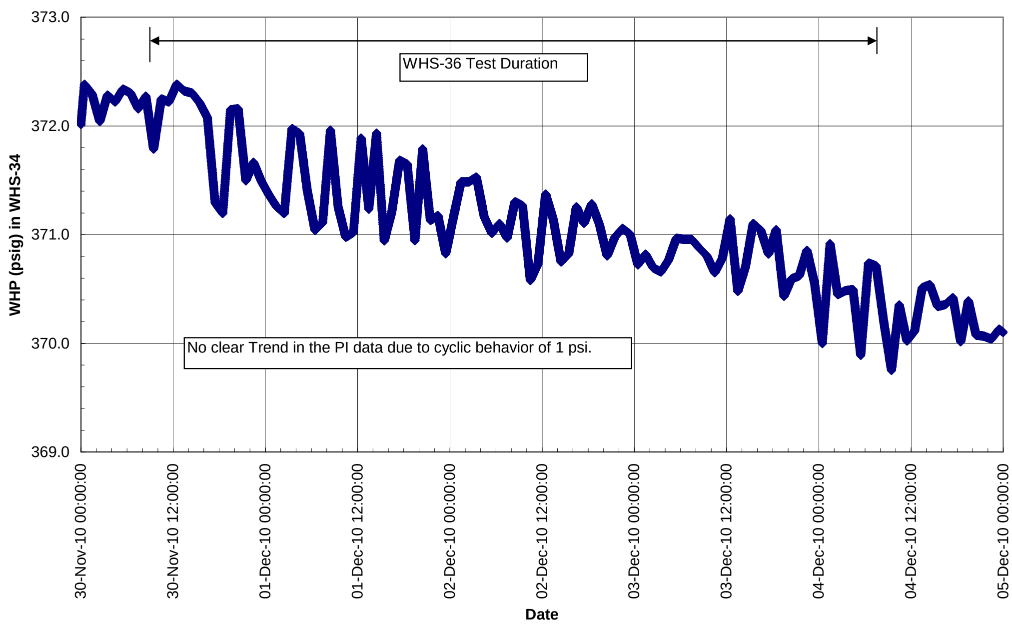


Figure 18: Pressure Interference in WHS-36 from WHS-34 Flow

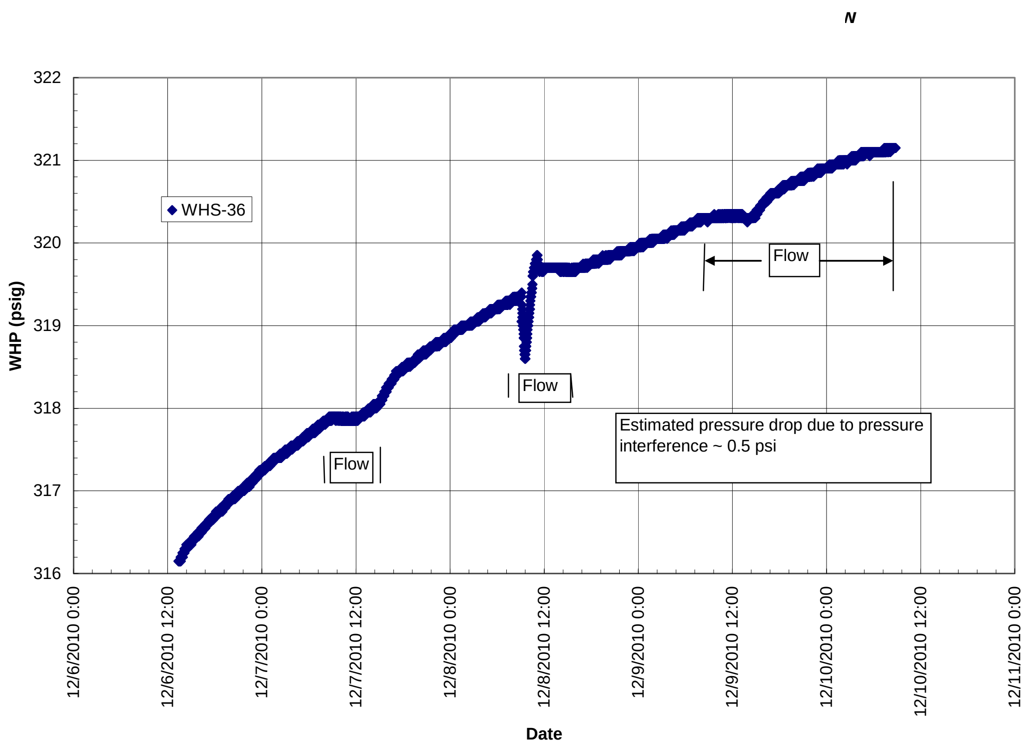
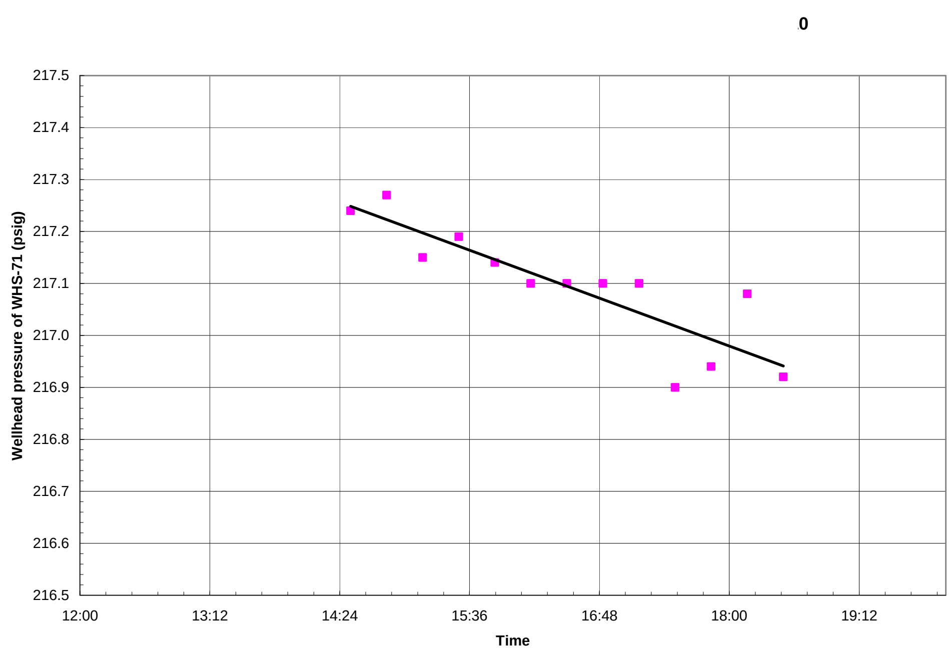


Figure 19: Shut-in Wellhead Pressure (WHP) at WHS-71 due to Interference from WHS-36 (6/14/10)



3.6 Long Term Static Pressure Monitoring

Static WHP data from WHS-36, obtained during July 15 to December 26, 2010 from Calpine's Production Information System (PI), are shown in Figure 20. This figure shows a continuous increase in its WHP. A pressure of 324 psig was measured on September 15, 2010 and 330 psig on November 18, 2010. The gaps in the WHP data in this figure are caused by the removal of the WHP transmitter from this well. Figure 21 shows SHWHP measured from December 5, 2010 to March 25, 2011.

Figure 20: Shut-in WHP of WHS-36 (7/15/2010 to 12/26/2010)

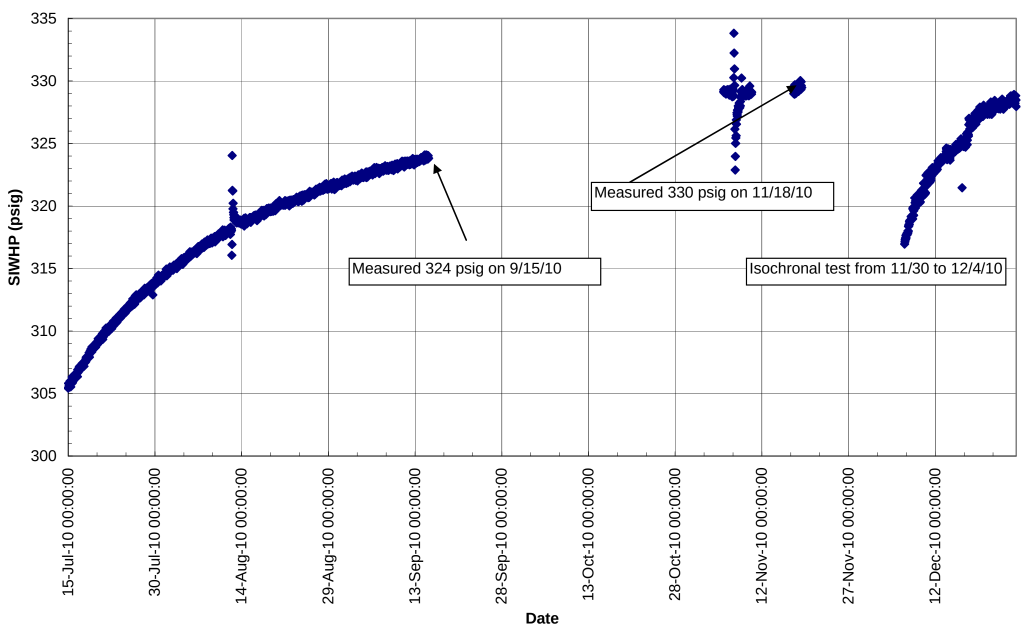
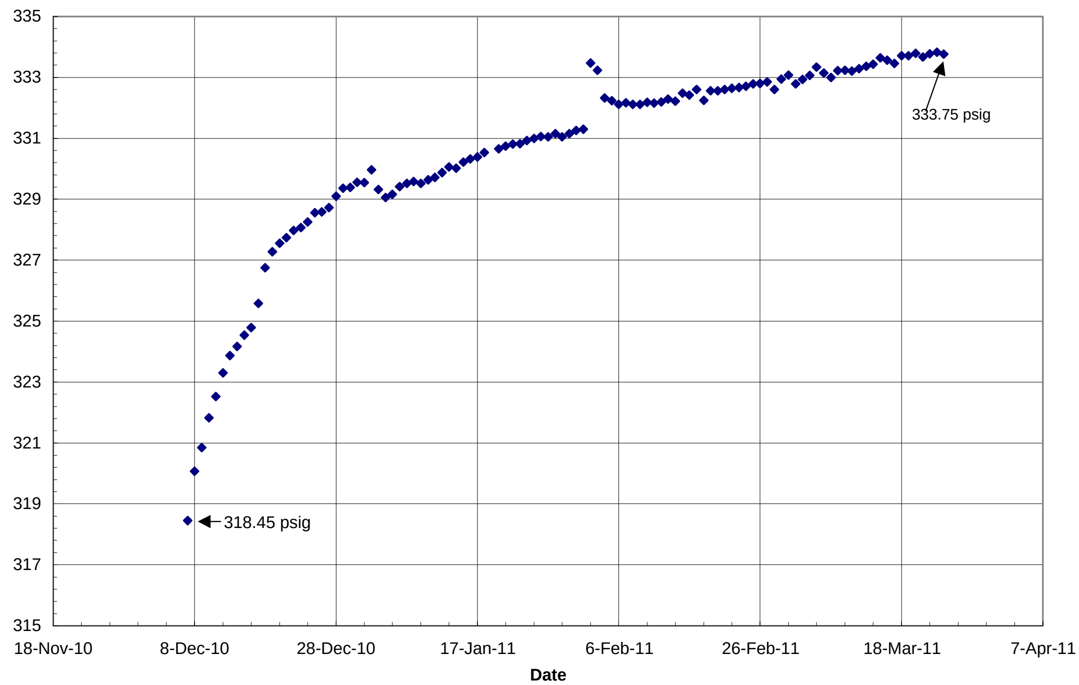


Figure 21: SHWHP December 5, 2010 to March 25, 2011



CHAPTER 4:
Steam and Fluid Sampling and Chemistry

Samples were collected for analysis of NCG, chloride (Cl), oxygen-18 (O^{18}) and deuterium (D) isotopes and major ions at various times during drilling and testing of WHS-36. During drilling, hydrogen sulfide (H_2S) was routinely measured in the steam flow by the logging geologists (mud loggers) and abated with chemical injection.

4.1 Noncondensible Gas (NCG)

Steam in The Geysers becomes enriched in NCG from the southeast to the northwest part of the reservoir, ranging from a low of less than 200 ppmw in the Unit 18 area to over 80,000 ppmw in the Aidlin area. Because of this trend and the generally high NCG concentrations (NCGC) observed during the operation of the CCPA power plant in the early 1990's, relatively high NCGC was anticipated in steam from WHS-36. In general, hydrogen sulfide (H_2S) concentrations in The Geysers reservoir vary as a function of total NCGC, as shown in Figure 22. Consequently, H_2S concentrations can be used during drilling as a rough indicator of total NCGC.

Figure 22: H_2S vs. NCG in The Geysers

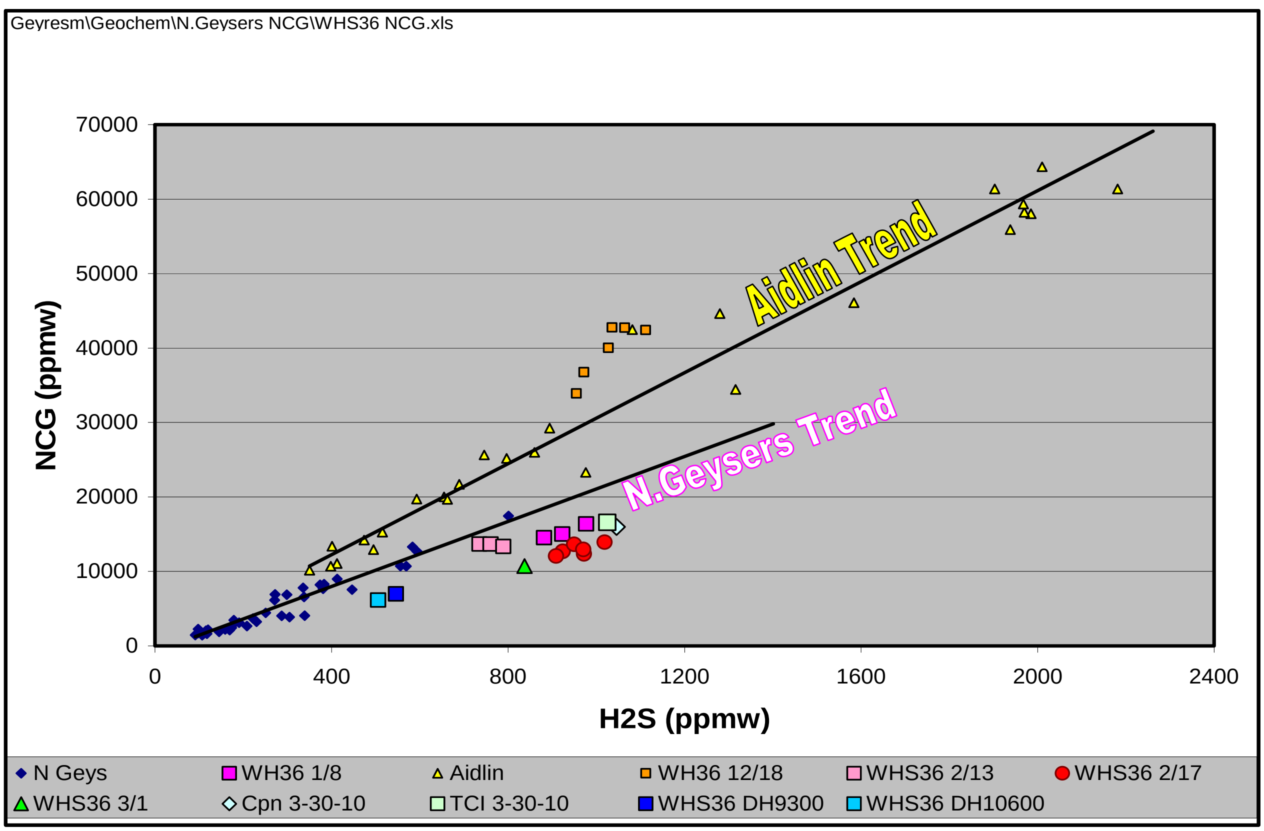


Figure 23 shows the flowing temperature profile measured on February 16, 2010 along with the depths of steam entries and the H_2S and ammonia (NH_3) concentrations in steam produced during drilling. It is apparent that high steam NCGC is associated with the two entries encountered at 6651' and 8259'. Steam entries from 9285' to TD are associated with a dramatic drop in H_2S (and therefore NCGC). The temperature log represents the actual temperature measured at the depth specified. The H_2S value represents the concentration that was measured at the surface while drilling at the depth specified. Consequently, the H_2S concentration is the blended (i.e. weighted) average of all the steam produced down to the specified depth.

Figure 23: Flowing Temperature, H_2S and NH_3 concentrations vs. Depth (2/16/10)

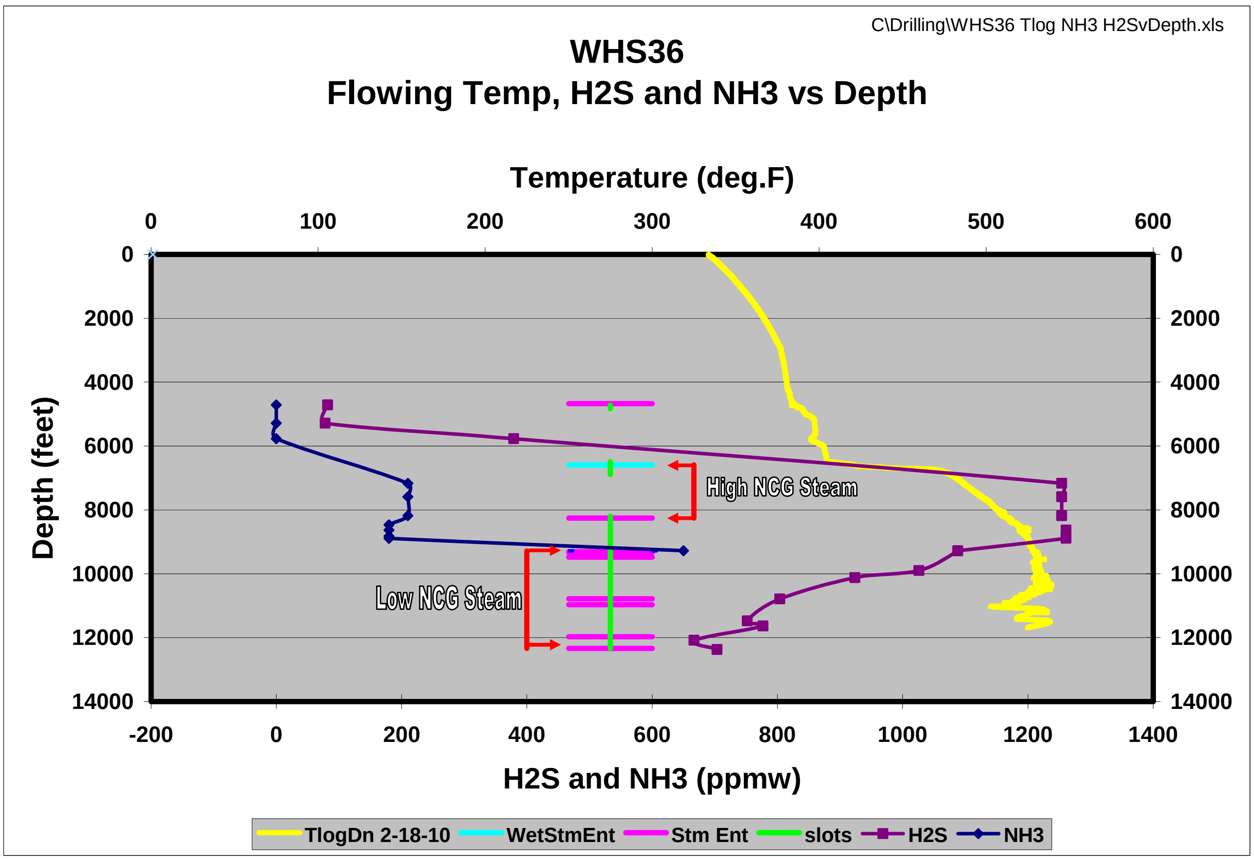
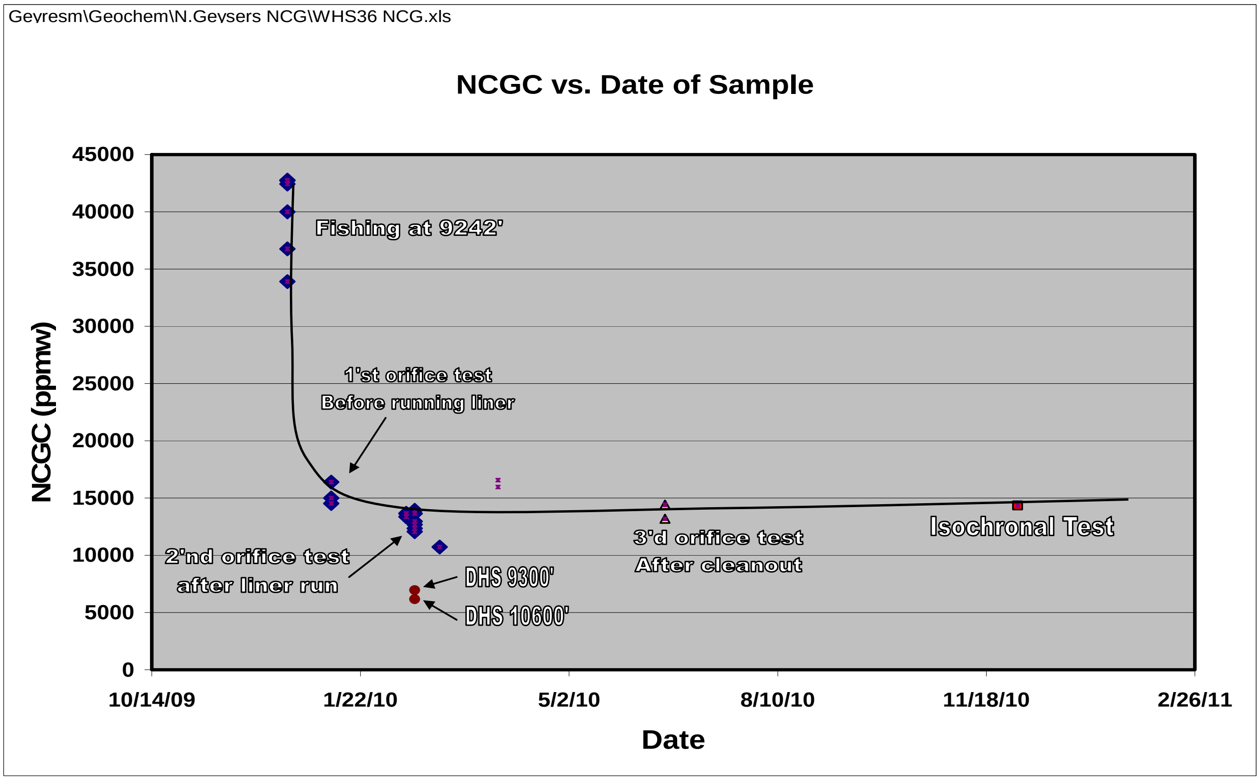


Figure 24 is a graph of steam NCGC versus the date the sample was collected. The samples taken at the end of the fishing job at 9242' reflect the high H_2S values (1100-1200 ppmw) measured by the mud loggers at that depth. On February 17, 2010, samples were collected during the drilling mud breakthrough event, at depths well below the breakthrough. Samples were collected with the down hole sampler (DHS), which is run on a wireline to the desired depth, opens, samples and closes. Samples were taken at depths of 9300' and 10,600' to determine how NCGC varies with depth. Since these samples were taken below the high NCGC interval shown on Figure 23, and therefore do not sample steam flowing from higher levels, they give a direct measurement of the NCGC of the deep WHS-36 steam. The DHS samples plotted on Figure 24 show that the deep steam has an NCGC of only 6000 to 7000 ppmw, and decreases with depth.

Figure 24: NCGC vs. Date of Sample

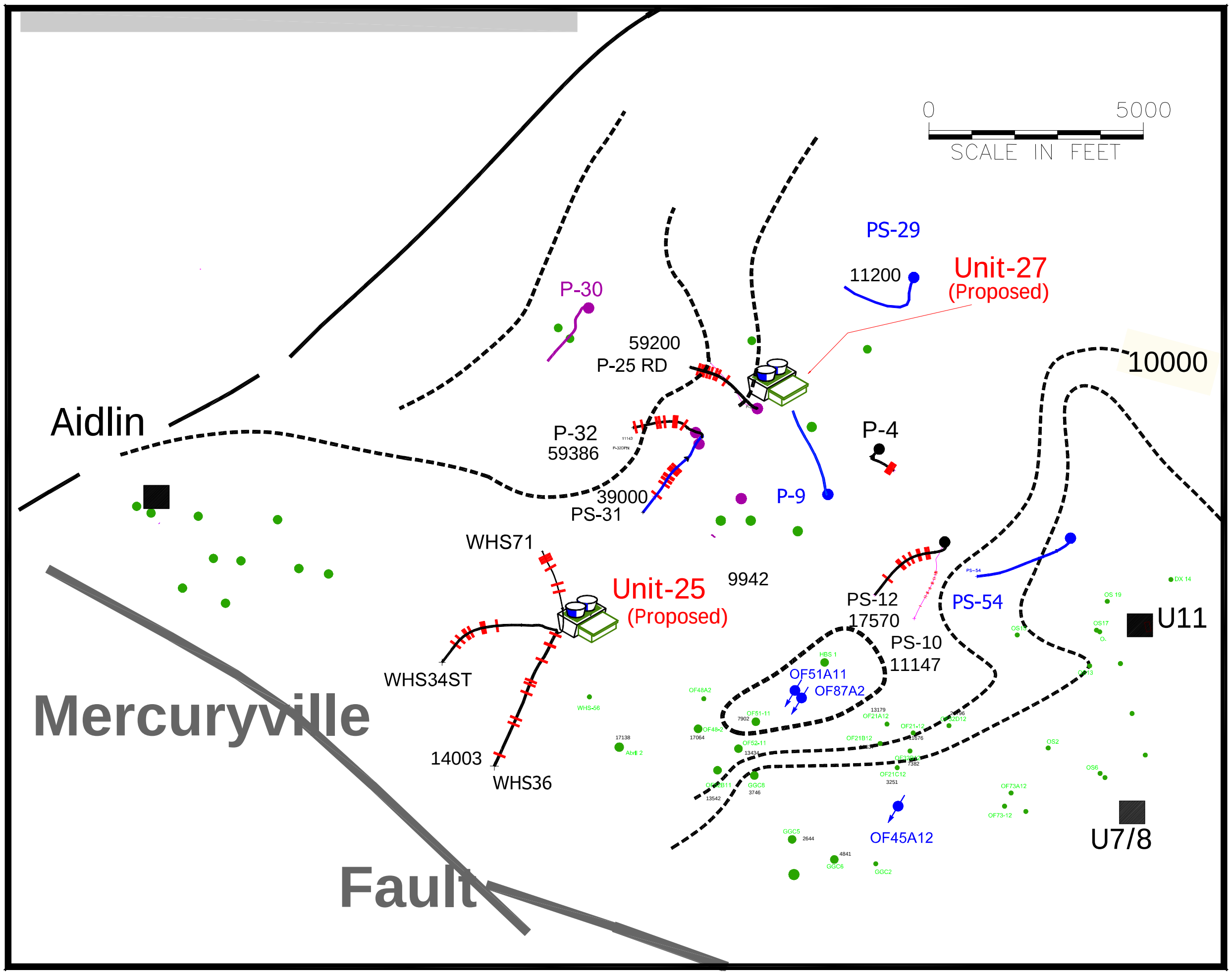


The dramatic decrease in NCGC with depth is possibly related to two factors. First, the shallow, gassy interval represented by the entries at 6588', 6651' and 8258' appears to rapidly deplete. At 9242', the NCGC was about 40,000 ppmw with wet tests recording 32 kph. By 11,000' the wet test flow rate was about 50 kph. Estimated from the H_2S values while drilling at this depth, the total flow NCGC was about 15,000 ppmw.

Second, the NCGC in this part of the field decreases laterally to the southwest, in the direction of the Big Sulphur Creek Fault, which is the southwest boundary of the reservoir. This NCGC gradient is documented by Beall, Wright and Hulen (2007). The bottom hole location of WHS-36 is located approximately 3500' SSW of the wellhead. Consequently, the wellbore traverses from an area of higher to lower NCGC in the reservoir. In the adjacent Aidlin area to the northwest, a similar very strong, lateral NCGC gradient exists. In the Aidlin steamfield, NCGC is known to range from about 10,000 ppmw to >80,000 ppmw over a distance of less than a mile.

Figure 25 shows a current contour map of NCGC for the northern Geysers, based on all of the NCG data acquired in the past two years of drilling in the Prati-Wildhorse area, as well as NCGC values obtained during the operation of the CCPA plant.

Figure 25: Prati-Wildhorse Area NCGC Values (ppmw)



4.2 Chloride

Chloride analyses of condensate samples collected from WHS-36 are included in Appendix C. Most of the samples were taken from a port on the line from the well head to the test muffler (the "blooie" line). The DHS was run at two depths in WHS-36 to determine the Cl content of deep steam produced from the high temperature reservoir (HTR).

The samples show extremely variable chloride concentrations. The low Cl measurements observed in some of the samples reflects low SH through the blooie line at the time the samples were taken. Liquid flow in the blooie line will normally run along the bottom of the horizontal pipe, effectively scrubbing the steam of volatile Cl and putting it into aqueous solution as Cl^-. With sufficiently long flow periods, the steam becomes highly superheated, the blooie line remains dry, and Cl is distributed in the steam, probably as hydrogen chloride (HCl) gas. The samples collected at 9300′ and 10,600′ contained 50.9 and 58.3 ppmw, respectively. A temperature sensor in the DHS recorded temperature well above 500°F at both sample depths, establishing that they were collected in the HTR. In both cases, sodium concentrations were well below 1.0 ppmw, and no other metal cations were present in significant quantities, establishing that the Cl-bearing phase was a volatile acid chloride, presumably HCl.

4.2.1 HCl-Bearing Steam

In the northwest Geysers the “normal”, 465°F steam reservoir is underlain by a HTR, which is also vapor dominated and has temperatures as high as 750°F. Early production from The Geysers reservoir consisted entirely of saturated steam produced from the normal 465°F reservoir, with generally low concentrations of NCG that varied systematically throughout the field (Gunderson, 1989; Beall, et al., 2007). Production of saturated steam was not associated with corrosion problems in well casings and surface piping. Corrosive steam with relatively high concentrations of volatile acid chloride has been produced from many wells since reservoir steam transitioned from saturated to superheated in the latter half of the 1980’s. Chloride concentrations measured in steam produced throughout the field now range from <0.025 ppmw to over 100 ppmw. Calpine considers chloride concentrations ≥ 0.40 ppmw to be “elevated” and chloride ≥ 1.0 ppmw to be “high”. Hirtz et al. (1991) noted that it is not clear whether the volatile chloride is transported in the vapor phase as ammonium chloride (NH_4Cl) or as HCl, although most authors have preferred the latter.

Haizlip and Truesdell (1992) and Walters et al. (1992) reported that steam from the HTR tends to have elevated NCGC and volatile chloride concentrations. Hirtz et al. (1991) reviewed the various origins proposed for volatile chloride, which include reactions involving concentrated brine and/or solid chloride phases at temperatures above 570 °F. However, such reactions are not necessary to account for the presence of volatile chloride since HCl gas is a component of many high temperature fumaroles in volcanic environments (White and Waring, 1963). Consequently, HCl gas in Geysers steam may emanate directly from a magmatic heat source. Whatever the genetic origin of the volatile chloride, its occurrence in produced steam signifies a dry (i.e. superheated) path from its source to the production well bore. Otherwise, the volatile acid chloride, whether NH_4Cl or HCl, will ionize, form acid and react with rocks in the reservoir.

Calpine has sampled wells producing high chloride steam with a DHS designed by Sandia National Laboratory in collaboration with Thermochem, Inc. (Beall, et al., 2009). The DHS utilizes a eutectic material with a high heat of fusion to condense steam and allow collection of a significant volume of both condensate and NCG. Samples collected with the DHS show that chloride is present at higher concentrations when the sample is taken in the well bore immediately above the deepest steam entries. The high chloride steam is believed to emanate from the HTR. Production of high chloride steam from wells that do not penetrate the HTR is an indication of vertical permeability connecting the HTR and normal reservoir.

4.3 O^{18} and Deuterium Isotopes of Produced Fluids

Isotope data collected from whole-rock, condensate and steam are included in Appendix C.

O^{18} and deuterium (D) isotope data often provide unique insight to problems relating to the origin and evolution of steam and water in geothermal systems. Figures 26 - 28 show D-O^{18} plots of the worldwide meteoric water line, trends for The Geysers steamfield, north Geysers condensate injection and water, and steam produced from the recently drilled Wildhorse wells. Water samples from Big Sulphur Creek and Squaw Creek are also plotted and, appropriately, fall very close to the meteoric water line.

Figure 26: Isotopic Trends in The Geysers

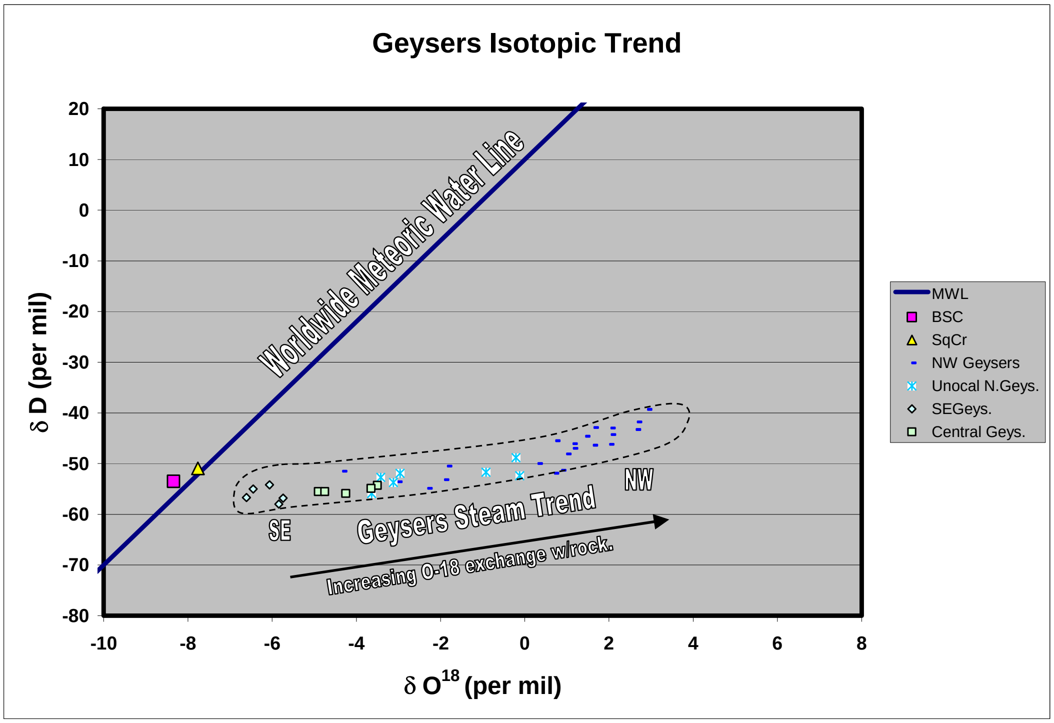


Figure 27: Geysers and Aidlin-Wildhorse Isotopic Trends

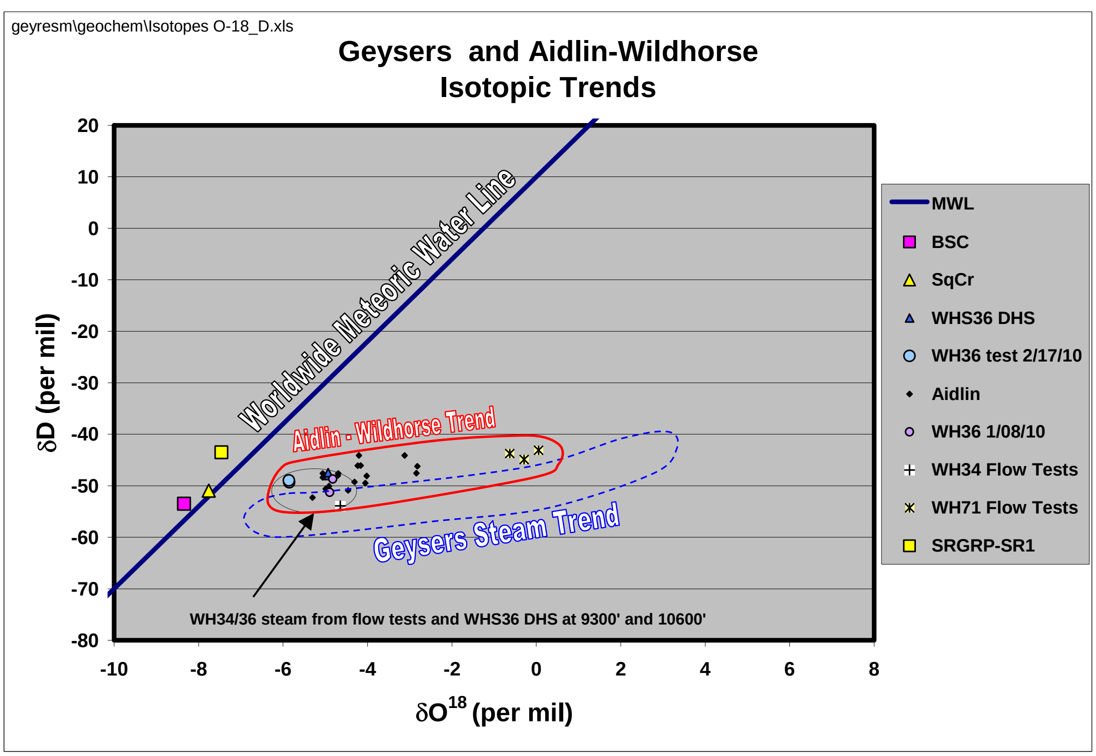
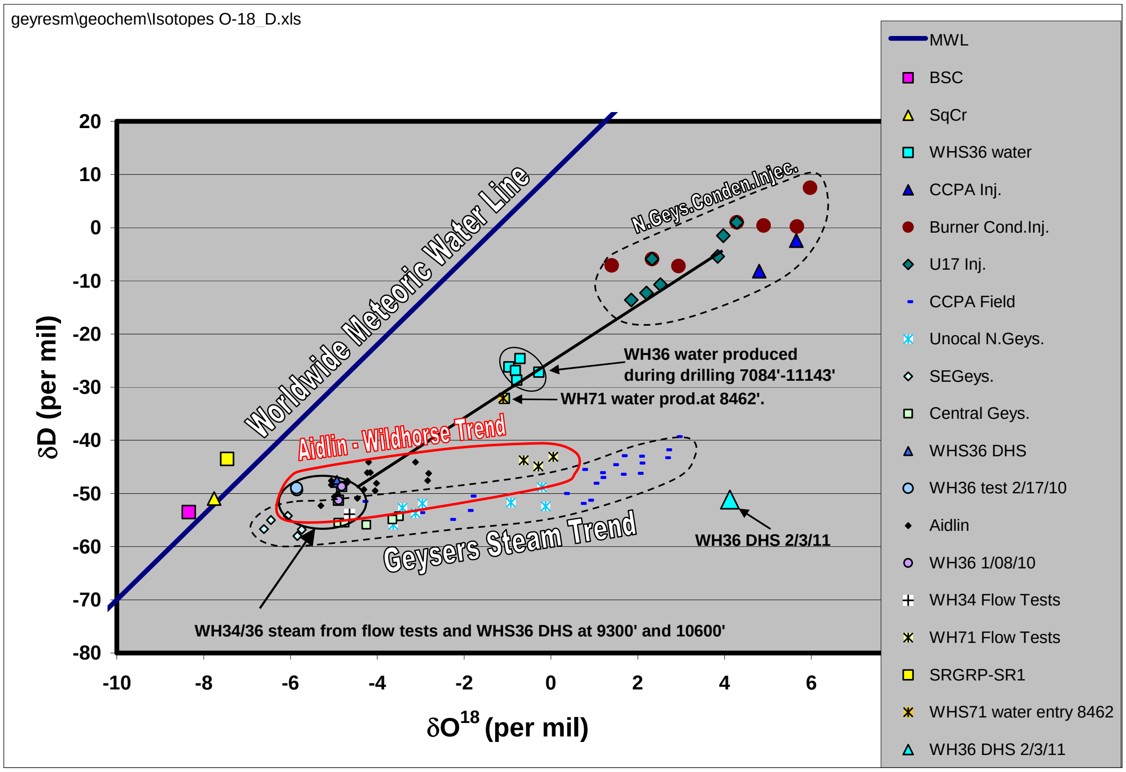


Figure 28: Isotopic Trends in the Geysers



Geysers steam displays the "oxygen shift" from the meteoric water line that characterizes nearly all geothermal fields (Figure 26). This shift establishes that geothermal fluids typically originate as meteoric waters that have been heated and have exchanged oxygen with silicate rocks, which are enriched in O^{18} relative to meteoric water. Franciscan greywacke in the Geysers caprock typically has O^{18} values of 11-13 per mil (off scale on the x-axis of Figure 26). In its "initial" or pre-development state, the least oxygen-shifted (i.e. least O^{18}-enriched) steam was found in the southeast part of the reservoir (Units 13, 16, 18). O^{18} values increase systematically from the southeast to the northern part of the former Unocal field (Units 5/6, 7/8, 11 and 17) and on into the former CCPA area (Truesdell et al, 1987; Gunderson, 1989). This is believed to be a consequence of a southeast to northwest "flush" of meteoric water that entered the reservoir from the Units 13 and 18 area when it transitioned from a 570°F, hot water system, to the current 465°F vapor dominated system that forms the "normal" Geysers reservoir.

The trend toward higher O^{18}-shifts in the northwest part of the field is not apparent in the Aidlin-Wildhorse area. Figure 27 shows that steam in the WHS-34/36 area is O^{18}-shifted to about the same extent as steam in the southeast Geysers, with slightly higher D. Aidlin steam is, on average, slightly more O^{18}-shifted than WHS-34/36 steam, but is not nearly as shifted as most of the steam in the CCPA field, which is plotted on the right-hand end of the Geysers Steam Trend. Isotopically, the Wildhorse-Aidlin area appears to have undergone a different evolution than the main Geysers field. The relatively small O^{18}-shift of the Wildhorse-Aidlin area may indicate a local source for the meteoric source water that invaded this part of the reservoir. WHS-71 steam appears to be isotopically more closely related to steam from the Prati (former CCPA) area. This is probably because WHS-71 is drilled to the north, in the direction of the Prati field.

Isotopic analyses were used to determine the origin of the water that has occupied the well below 10,000′ subsequent to the workover. Two possible origins were identified: (1) the water produced in moderate quantities (10-15 bbl/hr, 7-11 gal/min) throughout the drilling from a depth of 6588′ to approximately the depth of a steam entry at 10,780′ (Figure 28); and (2) breakthrough from a two phase system occupying the Mercuryville fault zone.

O^{18} and D isotopes of the water produced from 6588′ to below 10000′ have a distinctive isotopic composition suggesting mixing of roughly equal parts of "Aidlin-like" steam with condensate injection from the north Geysers (Figure 28). An obvious problem with this origin is that the nearest source of condensate injection would be the Aidlin field or former CCPA injection into Prati 8 and Prati 9. Both of these sources are separated by over a mile from WHS-36. Alternatively, the isotopic composition of the produced waters might have resulted from partial condensation and separation of steam and water phases at relatively low temperatures (<260°F) while ascending a relatively cool well bore. As noted above, all of the steam condensate samples collected during **testing** of WHS-36 (including those taken on February 17, 2010 at 9300′ and 10000′ with the DHS) have isotopic compositions similar to Aidlin steam.

In order to determine the origin of the water filling the lower part of the WHS-36 well bore, the DHS was run again on February 3, 2011 to a depth of 10,800′. The sample obtained was analyzed at two isotope labs that returned nearly identical analyses. The isotope values show clearly that the deep water that now occupies the lower part of the WHS-36 wellbore did not originate by either of the means described above for waters produced from 6588′ to about 10780′. It could only have originated by breakthrough from the deep entries in proximity to the Mercuryville Fault. The O^{18} of +4.1 (Figure 28) is the highest known value for O^{18} in The Geysers. Craig (1963) showed that in the Niland area of the Salton Sea Geothermal Field, the magnitude of the O^{18}shift from the meteoric water line increases with temperature. Moreover, the silica content of the sample recovered on February 3, 2011 with the DHS indicates a high temperature geothermal water, concentrated somewhat by boiling discussed below and illustrated in Table 1. These findings indicate that a two-phase geothermal system occupies the Mercuryville fault zone in the proximity of WHS-36.

4.4 Major Ion Chemistry

The major ion chemistry of the deep water zone in WHS-36, as determined by analyses of the February 3, 2011 downhole sample, is given in Table 1, along with analyses of various other geothermal brine samples shown for comparison. At 3758 milligrams per kilogram (mg/kg) the total dissolved solids (TDS) concentration of the WHS-36 sample is on the low end of the range shown (2140-7144 mg/kg). The TDS concentration of Roosevelt Hot Springs, Utah geothermal brine varies from 6000 to 7000 mg/kg. The range of TDS at the Coso geothermal field is somewhat greater at 4000 to 7000 mg/kg. The SiO_2 concentration found in the WHS-36 DHS sample is extraordinarily high at 1307 mg/kg, indicating concentration by boiling. Because the silica has been concentrated by boiling, the silica geothermometer is of no use in determining the temperature of the water at its origin. Applying the sodium, potassium, calcium (Na, K, Ca) geothermometer of Fournier and Truesdell to the WHS-36 analysis in Table 1 yields a temperature of 453°F. The DHS recorded a temperature of 488°F. The static PT survey on December 8, 2010 (Figure 13) recorded 490°F at the depth of sampling (10,800′). The extremely high O^{18} value of +4.1 implies that the water originates from a very high temperature source and is difficult to reconcile with the relatively low temperatures measured at sample depth.

Another anomalous aspect of the WHS-36 downhole sample is its high SO_4 value. High temperature geothermal waters are generally low in SO_4. Acid sulfate hot springs emanating from high temperature reservoirs derive their high SO_4 from oxidation of H_2S gas in a near surface environment. The corresponding deep brine is usually not enriched in SO_4. As shown in Table 1, the downhole sample contains 920 mg/kg of SO_4. The most likely explanation for the high SO_4 is that the air, which was pumped down the well on November 28-29, 2010 to attempt to blow it dry, has reacted with H_2S gas and formed SO_4.

Table 1: Major Ion Chemistry of the 2/3/11 WHS-36 Downhole Sample and Various Geothermal Brine Samples

	Geysers WHS36 DHS 2/3/2011	Glass Mtn. GM88A-28 9/23/2002	Glass Mtn. GM88A-28 11/4/2002	Glass Mtn. GM68-8 10/5/1989 Flash Corrected	Sulphur Bank Mine Clear Lake Bradley-1	Coso Well 73-19	Jorgensen-1 Unocal Thurston Lake	Roosevelt Hot Springs Utah Well 14-2
Analyte	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Sodium	888.94	943	715	924.2	770	2020	850	2150
Potassium	105.86	136	88.2	155.8	70	572	66	390
Calcium	7.80	10.8	11.4	23.0	2	49	7.7	9.2
Magnesium	0.69	0	0	0.28	<1		2.3	-
Lithium	2.88	0.45	3.71	7.43		27		
Strontium			0.17	0.0				
Boron	338	19.1	20.1	12.8	500	88	1150	29
Silica	1317	554	605	609.2	138*	595	420*	658
Chloride	803	1060	1080	1615.8	990	3739	636	3650
Fluoride	9.34	<0.25	0.62	5.3	2	2.2	2.1	-
Sulfate	920.81	290	73.6	40.8	10	15	53	78
Total Alkalinity (as HCO3-)	0	377	139	10.8	1420	44	1520	180
TDS (Calculated)	3758	3400	2740	3405	3764	7143	4287	7144

* Silica probably not kept in solution with acid preservative

CHAPTER 5:
Reservoir Geometry

It has long been known that the steam reservoir in the Aidlin area is several thousand feet deeper than that in the Ottoboni Ridge area to the southeast. The results of drilling the three confirmation wells provide some constraints on the reservoir geometry. Figure 29 shows the distribution of wells along the southwestern edge of the northern end of the field (Ottoboni Ridge to Aidlin).

Figure 30 is a cross section along line A-A′ (shown in Figure 29). Steam entries are shown by red tick marks. The top of steam (TOS) is shown by a dashed line. Based on drilling results, the TOS decreases in elevation from slightly below sea level at Ottoboni Ridge to about 6400′ below sea level at Aidlin. In the interpretation presented in Figure 30, most of the decrease in elevation occurs along a couple of steps near WHS-36. It is possible that a major normal fault (or two) drops the reservoir to greater depth to the northwest.

All four of the wells drilled since 2010 in the vicinity of WHS-36 (WHS-34, WHS-71 and WHS-56) failed to encounter significant amounts of steam above an elevation of about -6500′, in spite of a TOS several thousand feet higher. The interval between the TOS and the current (much deeper) productive reservoir is not well understood. Apparently, the interval was productive when Unocal did the original drilling in the Ottoboni Ridge area. Recent drilling suggests that this “depleted zone” extends at least as far east as WHS-56.

Figure 31 is a northeast-southwest cross section along line L-L′ (shown in Figure 29). Recent drilling/re-completion activity along that line includes wells Prati State 31, Prati 32, Prati 38, Prati 25 and Prati 9. These wells were initially completed by CCPA in the 1980′s and 1990′s. Steam entries encountered during the original drilling delineate the TOS (upper, solid line). The dashed line shows the current upper boundary of producible steam. As in Figure 30, the recent drilling activity supports the concept of a depleted zone. The reservoir conditions that led to the evolution of this zone have not been determined.

Figure 29: Well Locations

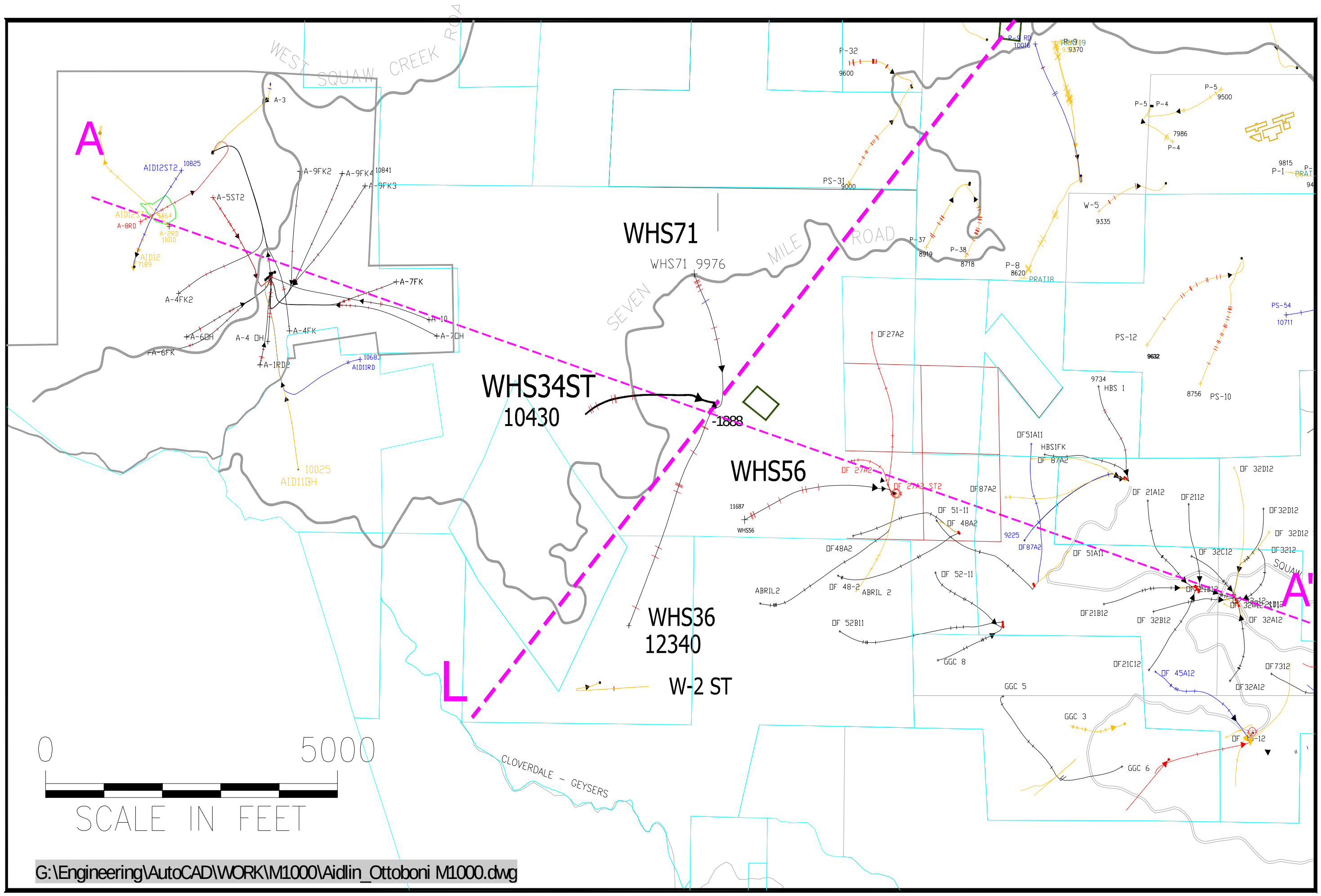


Figure 30: Cross Section A-A’

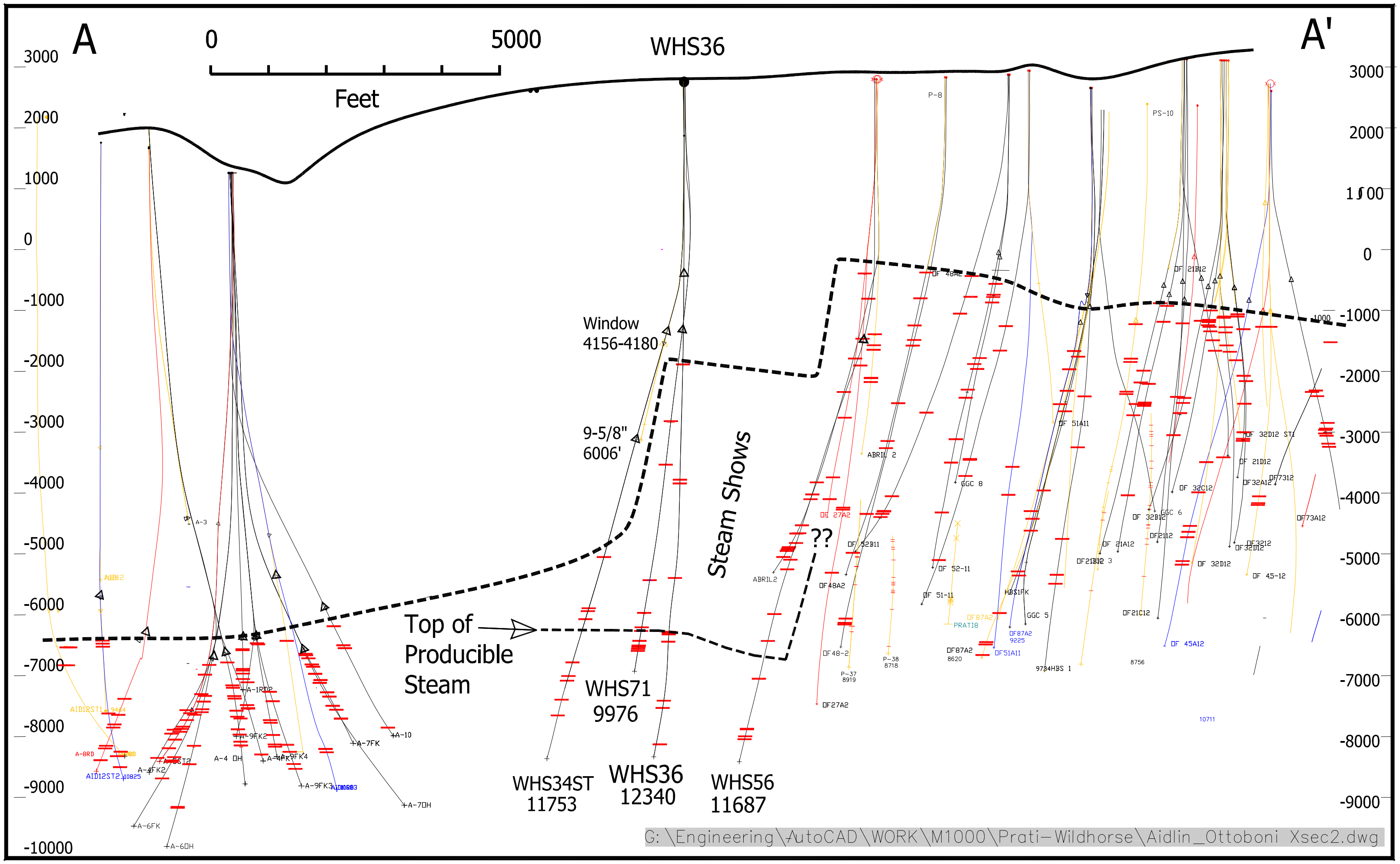
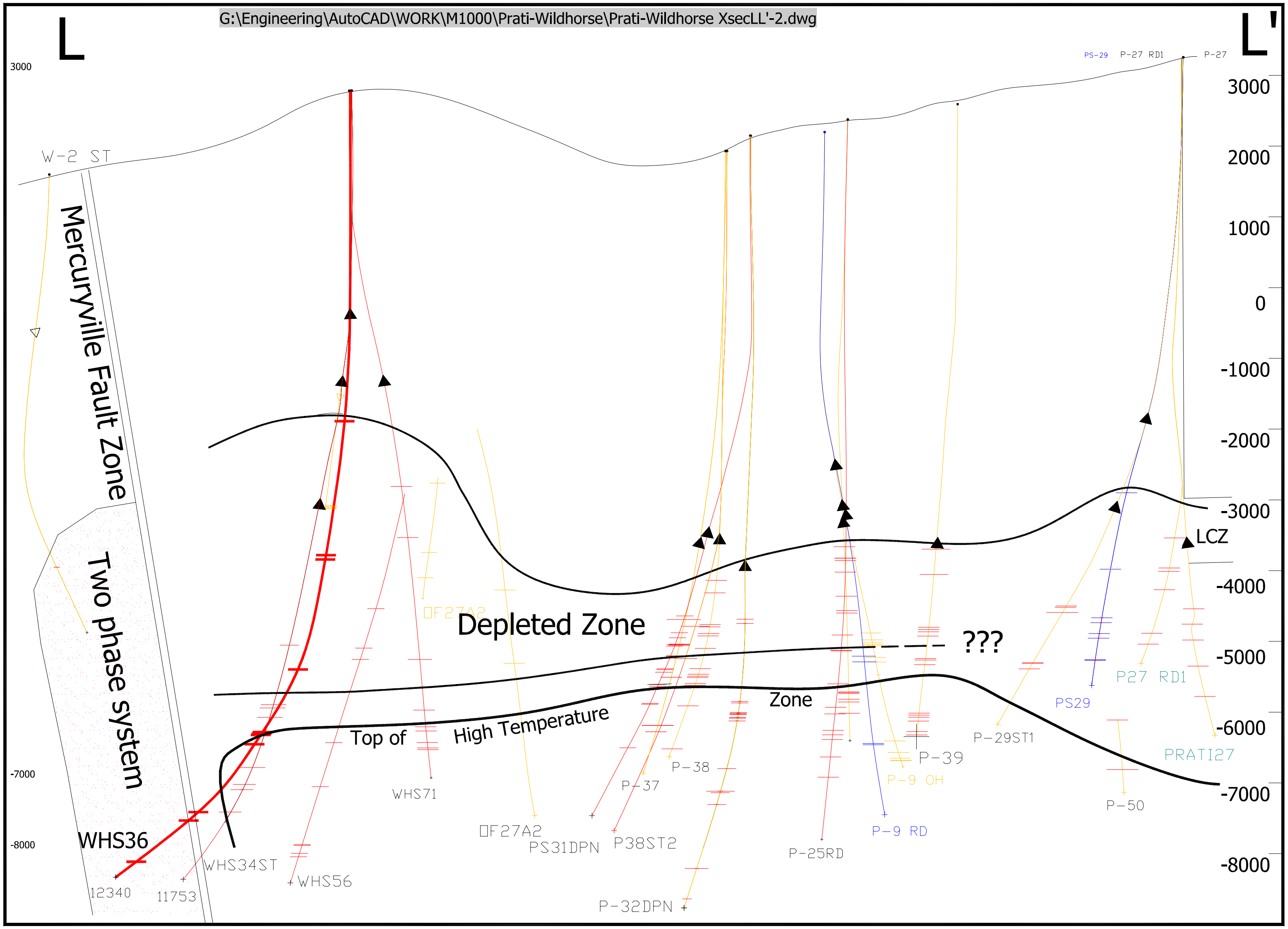


Figure 31: Cross Section L-L'



CHAPTER 6:
Conclusions and Recommendations

6.1 Reservoir Characterization

The following table summarizes WHS-36 test results that characterize the reservoir.

Table 2: Summary of WHS-36 Reservoir Test Results

	June 14, 2010	December 4, 2010
Flow (KPH)	32.8	27
WH Temp (^{o}F)	312.8	320
WH Press (psig)	63.8	79
Flow Rate KPH@100psig	31.1	26 *
Perm-Thickness (kH) millidarcy-ft	NA	10,400 **
Shut-In WHP (psig)	316	334
Total NCG (wt%)	1.4	1.5
H2S (ppmw)	919	906
Comments	Rig Test: 3.5" choke	3-day isochronal test

Notes:

* Water built up in the bottom of WHS-36 after the well repair and blocked several deep steam entries.

** kH values in the northwest Geysers area range from 5,000 to 300,000 millidarcy-ft. Common values range from 100,000 to 250,000 millidarcy-ft.

6.2 Economic Evaluation - Viability of the Buckeye Power Plant

WHS-36 did not confirm that construction of a Buckeye Power Plant is justified. The well is estimated to be able to produce about 1.5 MW of power. Current economic evaluation concludes that the deep wells in this area need to produce 3MW to 4MW to justify the cost of drilling. The cost of drilling the number of wells needed to supply a 33 MW plant is prohibitive.

6.3 Recommendations

Future power plant development on Ottoboni Ridge is not foreseeable. Steam produced from WHS-36 and other nearby wells may be piped to power plants to the southeast.

WHS-36 was completed as an injection well and may be used as such.

Because a power plant will not be built in the foreseeable future the collected data will not be used for power plant construction. However, the data is very important in gaining an understanding the surrounding steam fields.

6.4 Technology Transfer

All daily drilling reports, testing reports have been submitted to the California Division of Oil and Gas (DOGGR) open files accessible at htpp://geosteam.conservation.ca.gov/wellsearch/geowellsearch.aspx.

Drilling cuttings will be sent to the University of Utah EGI warehouse in Salt Lake City. This repository for samples from geothermal projects throughout the United State is available for public research.

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GLOSSARY

Original Term	Acronym / Abbreviation
Ammonia	NH_3
Ammonium chloride	NH_4Cl
Barrel	bbl
Barrels per hour	bph
California Division of Oil and Gas	DOGGR
California Energy Commission	CEC
Calpine Production Information System	PI
Central California Power Agency	CCPA
Chloride	Cl
Degrees Fahrenheit	°F
Deuterium	D
Differential pressure	DP
Downhole sampler	DHS
Enhanced Geothermal System	EGS
Feet	‘
Feet per minute	fpm
Geysers Power Company, LLC	Calpine
High temperature reservoir	HTR
Hydrochloric acid	HCl
Hydrogen sulfide	H_2S
Inch	"
Kilo pounds per hour	kph
Maximum reading thermometer	MRT
Maximum shut-in wellhead pressure	P*
Megawatt	MW
milligrams per kilogram	mg/kg
Nitrogen	N_2
Northern Sonoma County Air Pollution District	NSCAPD
Noncondensible gas (includes carbon dioxide and hydrogen sulfide)	NCG
Noncondensible gas concentration	NCGC
Northwest Geysers	NW Geysers
Oxygen-18	O^{18}
Parts per million by weight	ppmw
Percent by weight	%wt
Pound-force per square inch gauge	psig
Pounds per square inch	psi
Pressure - temperature	PT
Pressure-temperature-spinner	PTS
Public Interest Energy Research	PIER
Shut-in wellhead pressure	SIWHP
Superheat	SH

Temperature Gradient Holes	TGH
Top of steam	TOS
Total depth	TD
Total Dissolved Solids	TDS
Wellhead pressure	WHP
Wellhead temperature	WHT
Wildhorse 2	WH-2
Wildhorse State 34	WHS-34
Wildhorse State 36	WHS-36
Wildhorse State 71	WHS-71

APPENDIX A:
Internal Summary Reports

WHS-36 Test Chronology

Table 1: WHS-36 Test Chronolgy						
Date	**Time**	**Day**	**WHP-psig**	**WHT-F**	**Flow Rate**	**Comments**
					kph	
1/8/2010	15:55	Friday	91.5	328.5	43.8	3.5" choke before the liner in the well. Flow = 43.2 kph at 100 psig
2/12/2010	8:58	Friday	311.9			Started opening the well
	10:45					Fully opened. Continue to flow until Sunday night and abate H2S
	13:00				38.8	
2/13/2010	0:00	Saturday			38.8	
2/14/2010	0:00	Sunday			38.8	Shut-in 4:30 pm to install 2.5" choke
2/15/2010	0:00	Monday	237.7			
2/15/2010	7:00		252.95			
	7:20					Started opening up the well with 2.5" choke
	7:45		159.2	365.3		Well 100% open and making somewater
	8:00		154.0	363.0	34.7	Calculated flow (2.5" choke)
	10:00		227.8	294.2		Changing to 3" choke as well is trying to die
	11:00		249.6	144.9		
	12:13		172.4	344.6		Flowing it thru 3" choke
	15:30		114.9	337.3	39.0	Calculated flow (3.0" choke)
	16:00		106.7	334.6	36.5	Calculated flow (3.0" choke)
	16:30		105.4	334.2	36.1	Calculated flow (3.0" choke), 36.5 at 100 psig
2/16/2010	7:00	Tuesday	98.3	329.9	34.1	Ran P/T/S traverse at 50 fpm from 3,100' to 11,675' . Max T & P of 532°F & 220
						psig at 10,500'. Slugs of water of 4-6 bph every 15 minutes or so. WHP = +-3 psi
2/17/2010	7:00	Wednesday	96.9	329.4	33.7	Collected 3 downhole samples. Later muffler filled up with mud and cuttings from
						WHS 71. shut-in at 2100 hrs
2/18/2010	7:00	Thursday	231.5	46.3		Plan: Open up the well and vent without choke. Fix WHS-71 & set casing. Then
	15:41	Thursday	245.6	66.2		come back and run isochronal on this well
	mid night		13.3	222.7		Well is being vented to atmosphere after 3.:41 pm without choke plate. Shows
						small amount of drill contaminated water from WHS-71
2/20/2010	00:00 hrs					Well purging an estimate 30 bbls/hr with increased flow after steam chokes WH #
						36 well stopped flowing at 10:00 AM. Rigged up WH # 36 to air compressor.
						Pressured up and surged WH # 36 4 times before it would flow unassisted. Well
						has flowed with out air assistance since 8:00 pm at 15,200 #//hr and is still making
						30/35 bbls of water cut mud.
2/22/2010	mid night		239	187		WH # 36 started to flow at excessive rate, could not handle fluid flow, shut in well.
						Brought in 3 vacuum trucks, pumped air and brought in well. Ran in the hole , tagged
						bridge at 970' in WHS 71, cleaned out to 1000', WH # 36 began to flow fluid again ,
						3 vacuum trucks could not handle fluid .Shut in the well. Rigged up 6X6 pump to
						muffler in attempt to control the fluid flow from WH # 36
2/26/2010	mid night	Friday	76		15.2	Well flowing, Air turned off @11:00. Wet test flow rate
3/9/2010						P/T survey. Ran in hole to 6835, hit tight spot,traverse out of hole 50'/min
4/4/2010	12:45 PM	Sunday				Shut-in (1" bleed -unabated)
4/7/2010	12:00 PM	Wednesday	206.1			
4/20/2010						A camera was ran in the hole to 6830' and viewed blockage. The well was shut-in
5/21-25/10						Rig workover. Pulled out 7" upper liner. Cleaned the well upto 8785'. Installed the
						upper liner back.
6/14/2010	6:56 PM	Monday	63.8	312.8	32.8	Calculated flow (3.5" choke), 31.1 at 100 psig. SI WHP = 316 psig
						Wet test = 36.5 kph. Also collected WHPdata of WHS-71 and WHS-37
8/25/2010			321			Shut-in WHP (P*) based on July -Aug. 2010 Horner Plot = 328 psig
11/15/2010		Monday				Shut-in P/T survey up to 10,800'. Boiling water level from 9500' to 10,800 '.
11/18/2010						Measured SIWHP = 330 psig
11/28-29/10						Air injection from 340-380 psig. Total volume = 72*4 +72*3 = 504,000cft. Could not
						unload the well
11/30/2010		Tuesday	164.2	368.8	23.1	Started isochronal test with 4" orofice & 2" choke, Day =1 (9 am to 5 pm)
12/1/2010		Wednesday				Day 2. Orifice =4", choke = 2.5". DP out of transmitter range. Got built 5" orifice
12/2/2010		Thursday	117.4	348.4	27.4	Day 2 again (8 am to 4 pm). Orifice = 5", Choke = 2.5"
12/3/2010		Friday	86.5	325.4	29.7	Day 3, 24 hour (8 am to 8 am) Orifice =5", choke = 3".
12/4/2010		Saturday	78.5	319.5	27.3	Day 4, 8 am, Orifice =5", choke = 3". "n" = 1.1173, Flow at 100 psig = 26.1 kph
12/8/2010						Shut-in P/T to 10,800'. T= 490F, P= 604 psig. Water level below 10,278'. Dryingup
						Shut-in WHP (P*) based on December 2010 Horner Plot = 334 psig

TABLE - 1	R:\Drilling\Drilling 2009\Wildhorse #36\Flow ⁷		KPG	
			12/30/10	
WELL: **WHS36**	RIG TEST DATE=	**01/08/10**		
	DEPTH =	12,340 FT		

PRODUCTION FROM WILDHORSE LEASE

DATA INPUT:

WELLHEAD ELEVATION (FT) =	2753			
UPSTREAM PRESSURE (PSIG)=	91.35	331.1		
ATMOSPHERIC PRESSURE (PSI)=	13.3			
UPSTEAM TEMPERATURE (F)=	328.5	0.3285		
PIPE INSIDE DIA. (INCHES)=D=	12.96875		13	12.9375
ORIFICE DIAMETER (INCHES)=d=	3.5			
BETA = d/D =	0.2698795			
DENSITY (LBM/FT3) =	0.2390895			
Fa (for .2-1.1% c-steel)=	1.0036703			
YTSP(from formula)=	0.1443147			

FLOW (KLBM/HR) = 359*YTSP*D*D*Fa*(density*Pup)^0.5

CALCULATED STEAM FLOW RATE= **43,751** **lbm/hr**

				calculated	
beta	YtSp	ln (beta)	ln (YtSp)	YtSp	Error
0.11	0.0235	-2.207274913	-3.750755	0.0233054	-0.83%
0.125	0.03	-2.079441542	-3.506558	0.0302164	0.72%
0.15	0.044	-1.897119985	-3.123566	0.0437626	-0.54%
0.2	0.079	-1.609437912	-2.538307	0.0785098	-0.62%
0.25	0.123	-1.386294361	-2.095571	0.1235384	0.44%
0.3	0.177	-1.203972804	-1.731606	0.1789219	1.09%
0.4	0.315	-0.916290732	-1.155183	0.3209842	1.90%
0.5	0.51	-0.693147181	-0.673345	0.505082	-0.96%
0.6	0.74	-0.510825624	-0.301105	0.7315149	-1.15%

Regression Output:

Constant		0.725134	C1=	2.06500769
Std Err of Y Est		0.0113741	n=	2.0315576
R Squared		0.999926	YtSp=	c1*beta^n
No. of Observations		9		
Degrees of Freedom		7		
X Coefficient(s)	2.0315576			
Std Err of Coef.	0.0066042			

							Calculated
EQUATION FOR Fa		1	T	T^2	T^3	T^4	Fa
200	1.0017	1	0.2	0.04	0.008	0.0016	1.0014
250	1.0025	1	0.25	0.0625	0.015625	0.00390625	1.0023

Rig Test Reports

Rig Test	WHS-36										
						Ground	Atmospheric			Maximum	
Date	Time	WHP	WHT	Flow Rate	Choke size	Elevation	Pressure	Flow Rate (kph)	Flow Rate (kph)	shut-in pressure	Comments
		psig	°F	kph	inches	ft	psi	@100 psig	@125 psia	psig	
1/8/2010	16:00	91.4	328.5	43.8	3.5	2753	13.3	43.2	42.2	-	Tested without the liner
2/16/2010	**7:00**	**98.3**	**329.9**	**34.1**	**3**	**2753**	**13.3**	**34.0**	**33.2**	**-**	**Tested with liner installed**
2/12/2010										311.9	

Flow Test WHS-36 on June 14, 2010

SUMMARY

A flow test of WHS-36 was conducted for 4.75 hours on June 14 from 14:11 hours to 18:56 hours using a 3.5″ choke as presented in Figure 1. This well flowed 32.8 kph at a WHP and WHT of 63.8 psig and 312.8◦F respectively. Tecton was able to run their temperature probe closer to the center of the blooie line to get an accurate temperature reading. In contrast to earlier tests, we measured a superheat of 3.3◦F as presented in Table 1. This table also contains a chronology of events for this well. The flow rate normalized at 100 psig WHP is 31.1 kph.

Additionally, we measured the WHP of the nearby well WHS-71. This well exhibited a pressure drop of 0.3 psi as presented in Figure 2 (Figure 14 in text of report).

Added later (not part of original e-mail)

2/15/10: 36.1 kph at 105.4 psig & 334.2 F (3″ choke). This is saturated and 37.3 kph normalized at 100 psig WHP (Temp probe close to pipe wall)

6/14/10: 32.8 kph at 63.8 psig & 312.8F (3.5″ choke). This is superheated and 31.1 kph normalized at 100 psig WHP (Temp probe deep in the flow stream)

Tecton was able to move the temp probe deeper in the flow line compared to last time so we got better WHT data.

Air Up Report

Air Up Report WHS # 36

Sunday 11/28/2010

10:00 am- 2:00 pm, Psi start___340_____ Psi finish___380______
CF of air pumped__72,000_____

4:00 pm – 5:00 pm, Psi start____360___ Psi finish ___370______
CF of air pumped___72,000____

7:00 pm – 8:00 pm, Psi start_____360__ Psi finish____370_____
CF of air pumped__72,000_____

10:00 pm- 11:00 pm, Psi start_340_______ Psi finish___370______
CF of air pumped__72,000_____

Monday 11/29/2010

1:00 am – 2:00 am, Psi start____360___ Psi finish ____370_____
CF of air pumped__72,000_____

4:00 am – 5:00 am, Psi start___360____ Psi finish____370_____
CF of air pumped__72,000_____

7:00 am – 8:00 am, Psi start_360______ Psi finish______370___
CF of air pumped___72,000____

End Of Air UP

APPENDIX B:
Tecton Geologic Log

This Appendix is submitted under separate cover.

APPENDIX C:
Analytical Reports

Chloride and Boron Testing of Condensate

DBWELLNAME	DATE	TIME	BORON	CHLORIDE	SAMPLE POINT	SURVEYNAME	COMMENTS
WHS36	1/8/2010	13:53		16.70	blooie ln	RIG TEST	open hole, no liner installed
WHS36	2/13/2010	13:09		0.75	muff. Line	muffler flow test	collected before orifice plate installed
WHS36	2/17/2010	13:42		0.08	blooie ln	3" orifice test	DHS run same day, mud breakthrough from WHS71 drilling
WHS36	2/17/2010	17:05		0.07	blooie ln	3" orifice test	DHS run same day, mud breakthrough from WHS71 drilling
WHS36	3/1/2010	16:20		0.15	blooie ln		well flowing to muffler no orifice, no mud breakthrough at sampling time
WHS36_10600'_DHS	2/17/2010	10:33	14.10	58.30	DHS	Downhole sampler run#1	P=220.7psig, T=270.2C, Na=0.266mg/kg, SiO2=8.72mg/kg, pH=5.99
WHS36_9300'_DHS	2/17/2010	15:10	14.00	50.90	DHS	Downhole sampler run#2	P=219.1psig, T=275.2C, Na=0.745mg/kg, SiO2=4.43mg/kg, pH=5.85

Total NCG, Thermochem, Windsor, CA

DBWELLNAME	Date	Time	Total NCG ppmw	Gas/Steam (MPMM)	CO2 ppmw	CO2 mole%	H2S ppmw
WHS36	1/8/10	13:25	16388.94	8655.28	14128.06	67.96	977.39
WHS36	1/8/10	13:29	15005.15	7979.24	12888.12	67.11	923.42
WHS36	1/8/10	13:35	14532.97	7708.59	12501.67	67.35	882.38
WHS36	2/13/10	13:00	13655.99	7719.58	10795.90	58.04	735.31
WHS36	2/13/10	13:03	13649.20	7653.92	10844.53	58.79	760.81
WHS36	2/13/10	13:04	13358.65	7466.77	10631.83	59.07	789.55
WHS36	2/17/10	13:31	12683.45	7067.14	10031.50	58.84	924.19
WHS36	2/17/10	13:38	13932.96	7747.60	11077.85	59.34	1019.24
WHS36	2/17/10	13:42	13638.21	7536.74	10938.01	60.22	949.74
WHS36	2/17/10	17:20	12348.85	6950.18	9662.35	57.60	972.05
WHS36	2/17/10	17:20	12961.23	7222.29	10281.49	59.02	970.41
WHS36	2/17/10	17:20	12051.10	6813.84	9439.45	57.38	909.13
WHS36	3/1/10	16:45	10721.81	5832.99	8660.92	61.42	837.52
WHS36	3/29/10	11:55	16574.28	8846.50	14190.38	66.77	1025.23
WHS36_9242	12/18/09	22:30	36759.52	18490.00	33292.86	76.50	972.00
WHS36_9242	12/18/09	22:40	42769.34	21535.79	38956.56	77.33	1035.52
WHS36_9242	12/18/09	22:55	40005.08	20363.56	36068.56	75.57	1027.64
WHS36_9242	12/18/09	23:45	42721.00	21546.43	38868.21	77.12	1064.53
WHS36_9242	12/18/09	23:50	33903.00	16982.94	30663.43	76.48	955.06
WHS36_9242	12/18/09	23:55	42422.43	21424.45	38518.95	76.84	1112.13
WHS36_DHS 10600	2/17/10	10:33	6157.00	3426.00	5270.00	63.30	506.00
WHS36_DHS 9300	2/17/10	15:10	6962.00	3966.00	5970.00	62.00	546.00
WHS36_oriftst	6/17/10	15:30	14396.36	8240.48	9918.52	49.99	930.68
WHS36_oriftst	6/17/10	15:35	13191.59	7660.90	8954.53	48.48	920.27
WHS36_oriftst	6/17/10	16:10	14420.90	8301.11	9911.05	49.59	906.23
WHS36_oriftst	12/3/10	14:15	20282.00	12055.00	13130.00	41.86	659.00
WHS36_oriftst	12/3/10	14:36	18697.81	10944.90	11995.29	45.71	560.71
WHS36_oriftst	12/3/10	14:39	20943.69	12192.61	13698.05	46.97	580.94
WHS36_oriftst_N2correctd	12/3/10	14:15	14942.00	8595.00	13697.00	59.83	659.00

DBWELLNAME	Date	Time	H2S mole%	NH3 ppmw	NH3 mole%	Ar ppmw	Ar mole%	N2 ppmw	N2 mole%
WHS36	1/8/10	13:25	6.07	448.02	5.57	1.33	0.01	155.30	1.17
WHS36	1/8/10	13:29	6.21	450.02	6.06	-1.16	-0.01	83.88	0.69
WHS36	1/8/10	13:35	6.14	436.16	6.07	-1.12	-0.01	77.28	0.65
WHS36	2/13/10	13:00	5.11	453.01	6.29	15.12	0.09	1046.91	8.84
WHS36	2/13/10	13:03	5.33	456.57	6.40	15.18	0.09	962.33	8.20
WHS36	2/13/10	13:04	5.67	425.13	6.10	14.78	0.09	908.47	7.93
WHS36	2/17/10	13:31	7.00	565.88	8.58	9.60	0.06	645.87	5.95
WHS36	2/17/10	13:38	7.05	556.39	7.70	10.41	0.06	707.05	5.95
WHS36	2/17/10	13:42	6.75	537.32	7.64	9.40	0.06	666.71	5.77
WHS36	2/17/10	17:20	7.48	537.69	8.28	9.31	0.06	655.22	6.14
WHS36	2/17/10	17:20	7.19	586.29	8.70	8.84	0.06	606.61	5.47
WHS36	2/17/10	17:20	7.14	556.31	8.74	9.15	0.06	628.96	6.01
WHS36	3/1/10	16:45	7.67	502.19	9.20	5.13	0.04	334.30	3.72
WHS36	3/29/10	11:55	6.23	426.88	5.19	1.65	0.01	190.16	1.41
WHS36_9242	12/18/09	22:30	2.88	525.10	3.12	1.01	0.00	270.23	0.98
WHS36_9242	12/18/09	22:40	2.65	531.22	2.73	-1.52	0.00	300.11	0.94
WHS36_9242	12/18/09	22:55	2.78	495.08	2.68	3.37	0.01	486.92	1.60
WHS36_9242	12/18/09	23:45	2.73	500.33	2.57	-1.74	0.00	306.72	0.96
WHS36_9242	12/18/09	23:50	3.08	530.16	3.42	-1.04	0.00	227.40	0.89
WHS36_9242	12/18/09	23:55	2.87	528.73	2.73	0.99	0.00	298.48	0.94
WHS36_DHS 10600	2/17/10	10:33	7.85	178.00	5.53				
WHS36_DHS 9300	2/17/10	15:10	7.32	181.00	4.85				
WHS36_oriftst	6/17/10	15:30	6.06	596.38	7.77	36.65	0.20	2364.73	18.73
WHS36_oriftst	6/17/10	15:35	6.44	553.59	7.75	33.82	0.20	2189.15	18.62
WHS36_oriftst	6/17/10	16:10	5.86	581.60	7.52	36.26	0.20	2419.32	19.02
WHS36_oriftst	12/3/10	14:15	2.71	630.00	4.90			6103.00	30.57
WHS36_oriftst	12/3/10	14:36	2.76	459.90	4.53	77.55	0.33	4720.95	28.26
WHS36_oriftst	12/3/10	14:39	2.57	526.27	4.66	82.86	0.31	5100.04	27.47
WHS36_oriftst_N2correctd	12/3/10	14:15	3.71	630.00	6.71			178.00	1.22

DBWELLNAME	Date	Time	CH4 ppmw	CH4 mole%	DBWELLNAME	Date	Time	H2 ppmw
WHS36	1/8/10	13:25	567.08	7.48	WHS36	1/8/10	13:25	111.77
WHS36	1/8/10	13:29	553.84	7.91	WHS36	1/8/10	13:29	105.86
WHS36	1/8/10	13:35	534.34	7.89	WHS36	1/8/10	13:35	101.13
WHS36	2/13/10	13:00	486.61	7.17	WHS36	2/13/10	13:00	123.13
WHS36	2/13/10	13:03	492.53	7.32	WHS36	2/13/10	13:03	117.25
WHS36	2/13/10	13:04	474.09	7.22	WHS36	2/13/10	13:04	114.79
WHS36	2/17/10	13:31	404.32	6.50	WHS36	2/17/10	13:31	102.09
WHS36	2/17/10	13:38	448.21	6.58	WHS36	2/17/10	13:38	113.80
WHS36	2/17/10	13:42	428.03	6.46	WHS36	2/17/10	13:42	108.99
WHS36	2/17/10	17:20	406.29	6.64	WHS36	2/17/10	17:20	105.93
WHS36	2/17/10	17:20	402.02	6.33	WHS36	2/17/10	17:20	105.56
WHS36	2/17/10	17:20	402.97	6.72	WHS36	2/17/10	17:20	105.13
WHS36	3/1/10	16:45	304.10	5.91	WHS36	3/1/10	16:45	77.65
WHS36	3/29/10	11:55	619.18	7.99	WHS36	3/29/10	11:55	120.79
WHS36_9242	12/18/09	22:30	1566.71	9.87	WHS36_9242	12/18/09	22:30	132.61
WHS36_9242	12/18/09	22:40	1794.00	9.77	WHS36_9242	12/18/09	22:40	151.92
WHS36_9242	12/18/09	22:55	1766.21	10.15	WHS36_9242	12/18/09	22:55	157.69
WHS36_9242	12/18/09	23:45	1826.65	9.94	WHS36_9242	12/18/09	23:45	154.56
WHS36_9242	12/18/09	23:50	1407.47	9.63	WHS36_9242	12/18/09	23:50	119.51
WHS36_9242	12/18/09	23:55	1808.26	9.89	WHS36_9242	12/18/09	23:55	154.90
WHS36_DHS 10600	2/17/10	10:33	128.00	4.23	WHS36_DHS 10600	2/17/10	10:33	72.70
WHS36_DHS 9300	2/17/10	15:10	178.00	5.07	WHS36_DHS 9300	2/17/10	15:10	91.80
WHS36_oriftst	6/17/10	15:30	449.06	6.21	WHS36_oriftst	6/17/10	15:30	100.36
WHS36_oriftst	6/17/10	15:35	438.70	6.51	WHS36_oriftst	6/17/10	15:35	101.53
WHS36_oriftst	6/17/10	16:10	461.29	6.33	WHS36_oriftst	6/17/10	16:10	105.15
WHS36_oriftst	12/3/10	14:15	949.00	8.32	WHS36_oriftst	12/3/10	14:15	166.00
WHS36_oriftst	12/3/10	14:36	757.21	7.91	WHS36_oriftst	12/3/10	14:36	126.21
WHS36_oriftst	12/3/10	14:39	817.56	7.69	WHS36_oriftst	12/3/10	14:39	137.98
WHS36_oriftst_N2correctd	12/3/10	14:15	990.00	11.89	WHS36_oriftst_N2correctd	12/3/10	14:15	173.00

DBWELLNAME	Date	Time	H2 mole%	Comments
WHS36	1/8/10	13:25	11.74	
WHS36	1/8/10	13:29	12.03	
WHS36	1/8/10	13:35	11.89	
WHS36	2/13/10	13:00	14.45	
WHS36	2/13/10	13:03	13.88	
WHS36	2/13/10	13:04	13.92	
WHS36	2/17/10	13:31	13.07	
WHS36	2/17/10	13:38	13.31	
WHS36	2/17/10	13:42	13.10	
WHS36	2/17/10	17:20	13.79	
WHS36	2/17/10	17:20	13.23	
WHS36	2/17/10	17:20	13.95	
WHS36	3/1/10	16:45	12.02	
WHS36	3/29/10	11:55	12.41	
WHS36_9242	12/18/09	22:30	6.65	
WHS36_9242	12/18/09	22:40	6.58	
WHS36_9242	12/18/09	22:55	7.21	
WHS36_9242	12/18/09	23:45	6.70	
WHS36_9242	12/18/09	23:50	6.51	
WHS36_9242	12/18/09	23:55	6.75	
WHS36_DHS 10600	2/17/10	10:33	19.10	
WHS36_DHS 9300	2/17/10	15:10	20.80	
WHS36_oriftst	6/17/10	15:30	11.04	
WHS36_oriftst	6/17/10	15:35	12.00	
WHS36_oriftst	6/17/10	16:10	11.49	
WHS36_oriftst	12/3/10	14:15	11.64	air contaminated, pumped air into WHS36 11/28/10 for 22hrs
WHS36_oriftst	12/3/10	14:36	10.50	air contaminated, pumped air into WHS36 11/28/10 for 22hrs
WHS36_oriftst	12/3/10	14:39	10.33	air contaminated, pumped air into WHS36 11/28/10 for 22hrs
WHS36_oriftst_N2correctd	12/3/10	14:15	16.63	N2 corrected, air contaminated, pumped air into WHS36 11/28/10 for 22hrs

Whole Rock Oxygen-18 Isotopic Data, Southern Methodist University

WELL	MD DEPTH	O^{18} PERMIL	Repeat permil	Rock	Comment
WHS36	300	13.3	13.1	GW	Caprock
WHS36	1690	12.7		GW	Caprock
WHS36	1990	14.5	14.1	GW	Caprock
WHS36	2510	12.7		GW	Caprock
WHS36	2960	13.1	13.3	GW	Caprock
WHS36	3440	13.6		GW	Caprock
WHS36	4090	13.1		GW	Caprock
WHS36	4440	12.9		GW	Caprock
WHS36	4690	11.7	11.9	GW	Depleted NTR
WHS36	5340	13.7		GW	Depleted NTR
WHS36	5960	12.8		GW	Depleted NTR
WHS36	6590	10.3		GW	Depleted NTR
WHS36	6770	10.2	10.6	GW	Depleted NTR
WHS36	7670	11.6		GW	Depleted NTR
WHS36	8050	11.7	11.8	GW	Depleted NTR
WHS36	8900	9.3		GW	NTR
WHS36	9300	10.6	10.6	GW	HTR
WHS36	10010	7.7		GW	HTR
WHS36	11000	8.4		GW	HTR
WHS36	11960	10.2	10.4	GW	HTR

GW = Graywacke

NTR= "Normal" temperature reservoir $\pm$450 degF

HTR = High (>500 degF) temperature reservoir

Primary Producing Portion of Reservoir

Oxygen-18 and Deuterium Analysis Results of WHS-36, Water and Steam Condensate, Southern Methodist University

Oxygen-18 and Deuterium Analysis Results of WHS-36 water and steam condensate by Southern Methodist University, Dallas, TX

Calpine Well	Date Sampled	Time	Depth Feet	$\delta^{18}O$ (SMOW)	$\delta^{18}O$ Repeat	δD (SMOW)	δD Repeat	δD Repeat	SMU Sample #	Comment
WHS-36	12/4/09	15:00	7084'	-0.75	-0.67	-25.00	-24.3		CP 8-1	produced H2O
WHS-36	12/12/09		8890'	-0.97		-26.20			CP 8-2	produced H2O
WHS-36	12/14/09		9243'	-0.75	-0.88	-26.90			CP 8-3	produced H2O
WHS-36	12/29/09		10793'	-0.78	-0.79	-28.70			CP 8-4	produced H2O
WHS-36	12/30/09		11143'	-0.28	-0.27	-27.20			CP 8-5	produced H2O
WHS-36	1/2/10		11478	-1.03	-1.11	-31.70	-32.6		CP 8-6	produced H2O
WHS-36	1/8/10	13:42		-4.91	-4.88	-51.20	-51.4		CP 3-1	Rig Test
WHS-36	1/8/10	13:53		-4.81	-4.83	-48.70			CP 3-2	Rig Test
WHS-36	1/14/10	15:30	11300'	-4.81	-4.80	-51.50	-51.5		CP 8-1	
WHS-36	2/13/10	13:09		-5.93		-51.00			CP 8-2	flow test
WHS-36	2/14/10	13:42		-5.27		-48.10			CP 8-3	3" orifice test
WHS-36	2/17/10	17:05		-5.60		-46.20			CP 8-4	3" orifice
WHS-36	3/1/10	4:15		-5.34	-5.34	-52.20			CP 1-1	No Orifice
WHS-36	6/17/10	15:30		-5.29	-5.27	-47.70			Calpine 3-3	
WHS-36	12/3/10	14:15		-5.11		-50.80			Calpine 4-2	orifice test
WHS-36	12/3/10	14:15		-5.11		-50.80			Calpine 4-2	orifice test
WHS-36 DHS	2/17/10			-4.93		-48.02				DHS at 10600'
WHS-36 DHS	2/17/10			-4.93		-47.46				DHS at 9300'
WHS-36 DHS	2/3/11	11:29		4.12		-51.12				DHS at 10,800'

Note: Data highlighted in green are analyses of samples collected from water entries while drilling.
Data highlighted in yellow are analyses of samples from steam condensate collected at the wellhead during flow tests.
Data highlighted in orange are analyses of samples taken with the downhole sampler.